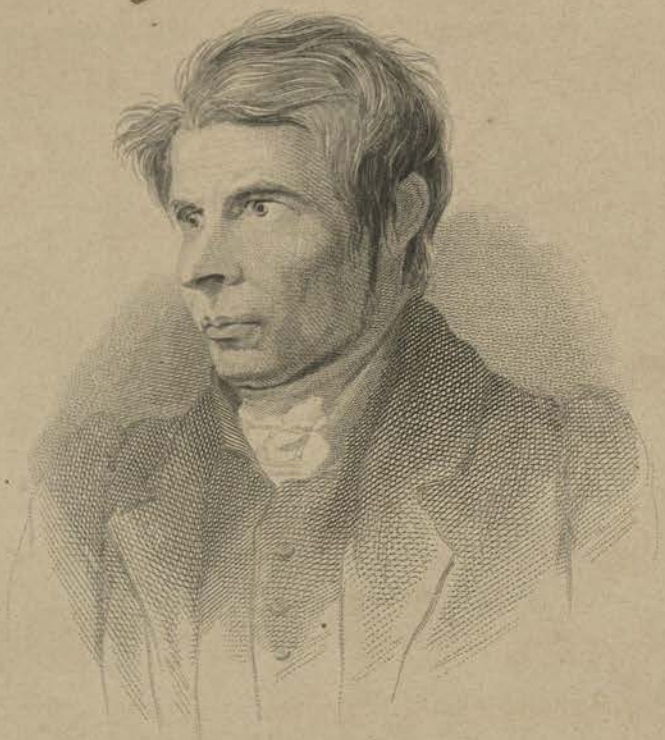
00080074

THE
ASIATIC SOCIETY OF BOMBAY
Town Hall, Bombay.

Digitized with financial assistance from the
Observer Research Foundation
on 25 April, 2019

ELEMENTARY PRINCIPLES



Thomas Tredgold

Crosby Lockwood & Co.ª 7. Stationers' Hall Court Ludgate Hill London. E.C.

ELEMENTARY PRINCIPLES

CARPENTRY:

A Treatise on the Pressure and Equilibrium of Timber Framing, the Resistance of Timber, and the Construction of Floors, Centres, Bridges, Roofs, etc.; with Practical Rules and Examples, and numerous Tables of the Scantlings of Timber for different purposes, the Specific Gravities of Materials, etc.

TO WHICH IS ADDED

AN ESSAY ON THE NATURE AND PROPERTIES OF TIMBER,

INCLUDING THE METHODS OF SEASONING, AND THE CAUSES AND PREVENTION OF DECAY, WITH DESCRIPTIONS OF THE KINDS OF WOOD USED IN BUILDING.

By THOMAS TREDGOLD, C.E.

WITH AN APPENDIX OF SPECIMENS OF

VARIOUS ROOFS OF IRON AND STONE.

Sixth Edition,

THOROUGHLY REVISED AND CONSIDERABLY ENLARGED,

By E. WYNDHAM TARN, M.A., ARCHITECT,

AUTHOR OF "THE SCIENCE OF BUILDING," "PRACTICAL GEOMETRY FOR ARCHITECTS," "TREATISE ON ROOFS," ETC

With Sixty-one Engravings, Portrait, and numerous Woodcuts.

E0074

LONDON:

CROSBY LOCKWOOD AND CO.,

7, STATIONERS' HALL COURT, LUDGATE HILL.

1885.

00080074

THE call for a new edition of TREDGOLD'S ELEMENTARY PRINCIPLES OF CARPENTRY is an evident proof that this work still maintains its position as the standard authority upon the subject among architects and engineers. Since this treatise was first published much light has been thrown upon the matters referred to therein by modern investigators and experimentalists; the present opportunity has therefore been embraced of making a complete revision of the work, and, to a great extent, of re-arranging its contents, so as to bring the information which it affords up to modern standards of knowledge.

The original division of the work into ten different sections has been retained, each section forming a complete treatise in itself, although frequent reference is made in them to the preceding and following sections.

SECTION I. is devoted to the explanation of the nature and laws of Pressure, and of the application of these laws to the designing of framing, &c. The modern method of calculating strains on framing by means of diagrams has been introduced, and also the strength and form of lock-gates for canals and docks.

SECTION II. treats of the Resistance of Timber; the principles upon which the several formulæ for strength and stiffness are based have been fully explained, as well as the mathematical investigations of the action of the forces, both of strain and resistance. The results of numerous experiments by various authorities on the strength of timbers have been given in tables, placed at the end of the section, from which constants are obtained by which the formulæ can be applied to practical purposes.

SECTION III. is upon the construction of Floors; the rules for calculating the strength and stiffness of the various forms of beams used in flooring have been demonstrated from the laws which are investigated in the previous sections. Tables of scantlings for floor timbers have been calculated by means of these rules for different spans. In this section the subjects of trussed-girders, bressummers, and flitch-girders have also been considered.

SECTION IV. treats upon the important matter of Roofs, and in the present edition has been much enlarged and entirely re-arranged; these structures being divided into trussed and untrussed roofs, while the subject of ancient Gothic roofs has been fully discussed. The modes of calculating the strength and thrust of arched and hammer-beam roofs are

given, as well as rules for finding the dimensions of the several pieces of which ordinary trussed roofs are composed. Tables of the scantlings for various spans have been calculated by the help of these rules.

SECTION V. is upon Domes and Cupolas, the thrust of which upon the supporting walls being calculated by analytical methods. Under this section will also be found a notice of timber spires and *flêches*, which may be considered as cupolas of a pyramidal form.

SECTION VI. treats of Timber Partitions and Frame-Houses; methods being given whereby the strains on the several pieces may be calculated and their requisite scantlings ascertained thereby.

SECTION VII. is occupied with the subject of the various temporary structures which are required to be erected by the carpenter, so as to enable the other artificers employed on a building to execute their several works. Under this heading are included centres for arches and bridges, scaffoldings, stagings, gantries, storing, and coffer-dams for building foundations under water.

SECTION VIII. is on Wooden Bridges and Viaducts, especial attention being directed to those which have been erected in various parts of England and North America, where many of the railway bridges and viaducts were formerly constructed of timber. This material has, however, of late years been generally superseded by iron, owing to its greater strength and durability.

SECTION IX. discusses the subject of the Joints by which frames of timber are united, and includes the iron straps, bolts, sockets, heads and shoes employed for the purpose of connecting the different parts of framing.

SECTION X. treats upon the nature and properties of Timber. In the present edition this section has been extensively revised, the Editor being indebted for much of his information to Rhind's *History of the Vegetable Kingdom*, Laslett's treatise on *Timber and Timber Trees*, and Fincham's *Outlines of Ship-Building*.

The Appendix is devoted to subjects which are only indirectly connected with Carpentry, and contains a brief notice of several modern roofs in which iron has been used in place of timber for the framework. It also contains an elaborate description of the method employed in building the ancient stone-vaulted roof of King's College Chapel at Cambridge, with a brief notice of the vaulting over Westminster Abbey.

E. W. T.

LONDON, *October*, 1884.

LIST OF WORKS REFERRED TO IN THE FOLLOWING PAGES.

ALBERTI.
BAKER'S "Principles of Statics and Dynamics."
BATSON "On Dry Rot" (*Trans. Soc. Arts*, Vol. XII).
BARLOW "On Strength of Materials."
BARLOW (P. W.) "On Lock-Gates" (*Trans. Inst. Civil Engineers*, Vol. I).
BELIDOR, "Architecture Hydraulique."
„ "Sciences des Ingénieurs."
BECKMAN, "History of Inventions."
BOWDEN, "Treatise on Dry Rot."
BRANDON, "Open Timber Roofs," and "Analysis of Gothic Architecture."
Brewster's Encyclopædia ("Hydrodynamics").
BRITTON, "Architectural Antiquities."
BUFFON, "Preuves de la Theorie de la Terre."
„ "Memoirs de l'Académie des Sciences," 1741.
CHAPMAN, "On the Preservation of Timber."
CLAYTON (J.), "Parochial Churches of Sir C. Wren," 1868.
DARWIN, "Phytologia."
DAVILER, "Cours d'Architecture."
DAVY (Sir H.), "Agricultural Chemistry."
DENNISON (Lieut. R. E.) "On American Timber" (*Trans. Inst. Civil Engineers*, Vol. II).
DOBSON, "Treatise on Foundations."
DOUGLAS (Sir H.), "On Military Bridges."
DUBUAT, "Principes d'Hydrauliques."
DUHAMEL, "Memoirs de l'Académie des Sciences," and "Transport des Bois."
Edinburgh Philosophical Journal.
Edinburgh Encyclopædia.
ELLIS, "Timber Tree Improved."
EMERSON, "Mechanics."
Encyclopædia Britannica ("Carpentry," "Bridge," "Dock").
Encyclopædia Metropolitana ("Naval Architecture").
EVELYN, "Silva."
FAREY, "River" (*Rees' Cyclopædia*).
FAREY, "Derbyshire Reports," Vol. II.
FINCHAM, "Outlines of Ship-Building," 1853.
First Report of the Commissioners of Woods and Forests, 1812.
FREZIER, "Coupe de Pierres."
GAUTHEY, "Construction des Ponts."
GIRARD, "Traité Analytique de la Résistance des Solides."
GOODEVE, "Mechanics."
GREGORY, "Mathematics for Practical Men."
HARVEY, "Diagonal Framing of Ships of War" (*Journ. Royal Inst.*, Vol. XXI).
HAKEWELL, "History of Windsor."
HASSENFRATZ, "Traité de l'Art du Charpentier," 1804.
HASKOLL, "Bridges and Viaducts."
HILL, "On the Construction of Timber."
HODGKINSON (Eaton), "Strength of Pillars" (*Phil. Trans.*, 1840).
HUTTON, "Course of Mathematics."
Journal of Science.
JOUSSE (Mathurin), "L'Art de la Charpenterie," 1751.

KING, "Observations on Ancient Castles."
KIRKALDY (D.), "Strength of Timber" (*Trans. Royal Inst. British Architects*, 1872).
KNIGHT, "Annals of Philosophy," Vol. XIV.
KNOWLES, "Inquiry into the Means taken to Preserve the British Navy.
KRAFFT, "Recueil de Charpente."
LACUNAR STREVELINENSE.
LASLETT (T.), "Timber and Timber Trees."
LESLIE, "Elements of Natural Philosophy."
LANGDORFF'S "Travels."
"Memoires de l'Académie des Science, Paris," 1726, 1729, 1738, 1773.
MOSSE, "On American Timber Bridges" (*Trans. Inst. Civil Engineers*, 1863).
MURRAY, "System of Chemistry."
MUSCHENBROECK, "System of Natural Philosophy," 1760.
NEVE, "Builder's Dictionary."
NEWTON (Sir I.), "Natural Philosophy."
NICHOLSON (P.), "Carpenter's New Guide."
" "Architectural Dictionary."
PALLADIO.
PAPWORTH, "Essay on the Causes of Dry Rot," 1803.
Philosophical Magazine.
Philosophical Transactions, Vol. XVII., 1805, 1818, 1820.
PLAYFAIR, "Natural Philosophy."
PONTEY, "Forest Primer."
PRICE, "British Carpenter."
Rees' Cyclopædia, ("River," by J. Farey).
" "Steam Engine."
RENNIE (G.) (*Philosophical Transactions*, 1818).
RHIND, "History of the Vegetable Kingdom."
ROBISON, "Carpentry," "River" (*Encyclopædia Britannica*, 1839).
" "Mechanical Philosophy."
RONDELET, "L'Art de Batir."
SEMPLE, "On Building in Water."
SERLIS, "Tutte l'Opere di Architettura," 1600.
SMEATON'S "Reports."
SMITH, "Specimens of Ancient Carpentry," 1786.
STUART'S "Athens."
STEVENSON (D.), "Civil Engineering of North America," 1859.
TARN, "The Science of Building." Second Edition, 1882.
" "Practical Geometry for the Architect, Engineer, Surveyor, and Mechanic." Second Edition, 1882.
" "Elementary Principles of Carpentry, 1873.
" "Stability of Domes" (*Proceedings of the Royal Society*, 1866, and *Civil Engineer and Architect's Journal*, 1868).
" "Elementary Treatise on the Construction of Roofs," 1882.
THUNBERG'S "Travels."
TREDGOLD, "On Strength of Iron."
Transactions of the Society of Arts, Vols. XXI. and XXXIII.
" " *Royal Institute of British Architects*, 1855, 1857, 1865, 1872.
WADDINGTON (Colonel), "Papers of Royal Engineers."
WATERHOUSE, "Manchester Assize Courts" (*Trans. Royal Inst. British Architects*, 1865).
WARE, "Complete Body of Architecture."
WIEBEKING, "Traité d'une Partie Essentielle de la Science de Construire les Ponts."
WATSON, "Chemical Essays."
WILCOX, "Papers on Naval Architecture."
YOUNG (Dr. Thomas), "Natural Philosophy."

CONTENTS.

INTRODUCTION.

ARTICLE		PAGE
1.	Theory of Carpentry	1
2.	Stability of Position	1
3.	„ Resistance	2

SECTION I.

ON THE EQUILIBRIUM AND PRESSURE OF BEAMS.

4.	Introductory Remarks	3
5.	On the Composition and Resolution of Forces	3
6.	Two weights balanced by a single weight	4
7.	Triangle of Forces	4
8.	Relation between Forces and the Angles they make with each other	4
9.	Strain on a Framework of Beams	5
10.	Resolution of Strains on Beams	5
11.	Beams placed in a Circle	5
12.	On the Effect of Position	6
13.	To measure the Strains in a Framed Truss	6
14.	Strains on a King-Post Roof Truss	6
15.	„ Queen-Post Roof Truss	6
16.	Maxwell's method of Diagrams	7
17.	Application of Maxwell's method of Diagrams to a King-Post Roof	7
18.	On Framed Levers	10
19.	Effect of Position further considered	11
20.	Strain on the Jib of a Crane	11
21.	„ „	12
22.	To distinguish Ties from Struts	12
23.	Strains in Lattice Framing	13
24.	To find the Resultant of a System of Forces	14
25.	Polygon of Forces	15
26.	Resolving a Force in different directions	15
27.	Strains of Ribs disposed in a Circle	15
28.	Resistance of Domes	16
29.	Framing contrived so that load rests on two or more points	16
30.	On the Centre of Gravity	16
31.	„ „ of Geometrical Figures	17
32.	„ „ of a Trapezium	18
33.	„ „ by Mechanical Methods	18

ARTICLE		PAGE
34.	Body supported at Centre of Gravity	19
35.	On the Pressure of Inclined Beams	19
36.	Minimum Oblique Pressure on Rafters...	19
37.	Horizontal Thrust from Oblique Pressure	19
38.	Angle of Abutment, how calculated	20
39.	Beam moving between two Planes	20
40.	Rule for Horizontal Thrust of Inclined Beam	20
41.	Strain on a Strut	21
42.	Directions of Pressures vary with position of Supports	21
43.	Perpendicular Pressure on Points of Support	21
44.	On the Strain upon Horizontal Beams	22
45.	Beam fixed at one end	22
46.	„ supported at two ends	22
47.	„ loaded at any point	23
48.	Load uniformly distributed	23
49.	„ at two or more points	23
50.	Beam supported at three or more points	24
51.	On Stress from the Pressure of Fluids	24
52.	On the Stress on the Gates of Locks	25
53.	Best Angle for Lock-Gates	26
54.	Strength of Lock-Gates when Curved	26
55.	„ „ „ Straight	26
56.	Mr. P. W. Barlow's Table of Scantlings for Lock-Gates	27
57.	On the Equilibrium of an Assemblage of Beams...	28
58.	On the Points of Fracture in a System of Framing	28
59.	Sir R. Sepping's Framing for Dock Roofs	28
60.	Position of Points of Fracture in Sir R. Sepping's Framing for Dock Roofs...	29
61.	„ „ „ „ „	29
62.	Load Balanced so as to have no Tendency to Fracture	29
63.	Stable and Tottering Equilibrium	30
64.	To determine the Curve of Equilibrium	30
65.	Example of the Curve of Equilibrium when load is uniformly distributed	30
66.	„ „ when weight is at any point	31
67.	„ „ „ distributed	31
68.	Curve of Equilibrium for a Cupola	32
69.	Example of Curve of Equilibrium for a Cupola when weight is distributed	32
70.	„ „ „ „ „	32
71.	„ „ „ when Cupola has a lantern	33
72.	Remarks on the Curve of Equilibrium	33
73.	General Observations on Designing Framing	34

SECTION II.

ON THE RESISTANCE OF TIMBER.

74.	Introductory Remarks	35
75.	Definitions and General Principles	36
76.	Difference between Stiffness and Strength	36
77.	Extension and Compression	37

ON THE RESISTANCE TO EXTENSION.

ARTICLE		PAGE
78.	On the Stiffness of Beams to Resist Extension	37
79.	„ Strength „ „	38

ON THE RESISTANCE TO CROSS STRAINS.

80.	On the Stiffness of Beams to Resist Cross Strains	38
81.	Neutral Axis of Beams	38
82.	Law of Deflexion in Beams	39
83.	Deflexion of Beam supported at each end and loaded at middle	40
84.	Stiffest Beam out of a Round Tree	41
85.	Resistance to Flexure of Beam supported at each end	41
86.	Rule for Proportion of Breadth to Depth	42
87.	To find Depth of a Beam of given length	42
88.	Experiments on Oak	42
89.	Rules for Stiffness of Beams	43
90.	Scantling of Beam to bear a given weight, when breadth is given	43
91.	„ „ „ depth is given	44
92.	„ „ „ ratio of breadth to depth is given	44
93.	„ „ „ beam is inclined	44
94.	Beam fixed at both ends and loaded in middle	45
95.	On the Stiffness of Cylinders supported at both ends	46
96.	„ „ Beams uniformly loaded	47
97.	Analytical Method of finding Deflexion	47
98.	On Stiffness of Beams supported at one end	48
99.	Formula for „ „	49
100.	Weight uniformly distributed over the length	50
101.	On the Strength of Beams to resist Cross Strains	50
102.	„ „ „ supported at both ends	51
103.	„ „ Cylinders	52
104.	Strongest Beam out of a Round Tree	52
105.	Experiments on Strength of Beam supported at both ends	53
106.	Rules for Strength of Beam supported at both ends, load at middle	53
107.	„ „ Solid Cylinder, load at middle	53
108.	„ „ „ load distributed	53
109.	Strength of Beam supported at one end	54
110.	Resistance to Detrusion or crushing across	54
111.	Rule and Example of Resistance to Detrusion or crushing across	54
112.	On Bent Timber	55

ON THE RESISTANCE TO COMPRESSION.

113.	Experiments of Rondelet and Rennie	55
114.	Rule for Load on a Short Pillar	56
115.	Hodgkinson's Experiments	57
116.	On the Resistance to Compression at Joints of Framing	57
117.	On the Strength of Columns and Posts to Resist Flexure	58
118.	Stiffest form of Rectangular Post	59
119.	Pressure down Inclined Beams	59
120.	„ „ when the Pressure is not down the Axis	59
121.	Pillar of Uniform Strength throughout	59
122.	Girard's Experiments on Stiffness of Beams to Resist Compression	60

ARTICLE		PAGE
123.	Dr. Young's Experiments on Stiffness of Beams to Resist Compression	60
124.	Practical Rules for Strength of Columns	62
125.	To find Scantling of Post for a given Load	62
126.	„ „ Curved Post „	62
127.	Hodgkinson's Experiments on long Pillars	63
128.	„ „ „	63
129.	„ „ Strength of Short Pillars	63
130.	Strength of Curved Ribs	64
131.	Rule for the Scantling of Curved Ribs	64
132.	Rule and Example of Scantling of Curved Ribs	64
133.	Strength of Story Posts	65
134.	On the Resilience of Timber	66

TABLES OF EXPERIMENTS ON STRENGTH OF TIMBER.

TABLE	I.	Tensile Strength of different woods	67
„	II.	Laslett's Experiments on the Tensile and Transverse Strength of different woods ...	68
„	III.	Cohesion perpendicular to Fibres	68
„	IV.	Cohesive Force of Iron	69
„	V.	Stiffness of Oak Beams supported at both ends	69
„	VI.	„ Fir „ „	71
„	VII.	„ various woods „	72
„	VIII.	Barlow's Experiments on Strength of various woods supported at both ends	73
„	IX.	Strength of Beams of various woods supported at both ends	73
„	X.	„ American Timber	75
„	XI.	Stiffness of Beams supported at one end	75
„	XII.	Strength „ „	76
„	XIII.	Crushing Strength of Short Pieces	77
„	XIV.	Lamandé's Experiments on Crushing Strength	78
„	XV.	Girard's „ „ „	79
„	XVI.	Constant numbers for Dimensions of Columns	79
„	XVII.	Hodgkinson's Experiments on Square Pillars	80
„	XVIII.	Kirkaldy's „ „ „	81
„	XIX.	Scantlings of Story Posts, to carry two stories	81
„	XX.	„ „ „ three „	82
„	XXI.	„ „ „ four „	82
„	XXII.	„ „ „ five „	82

SECTION III.

ON THE CONSTRUCTION OF FLOORS.

ARTICLE		PAGE
135.	Naked Flooring of various kinds	83
136.	Robison's Experiment on Strength of Floors	83
137.	On Single-Joisted Floors	84
138.	On Framed Floors. Girders	85
139.	To find the Scantling of a Girder	86
140.	Flitch Girders	87
141.	Trussed Girders	88

ARTICLE		PAGE
142.	Trussed Girders, with oak truss	88
143.	„ „ wrought-iron	89
144.	Examples of Framed Girders	89
145.	„ Built „	90
146.	Bressummers	91
147.	Binding Joists, to carry a floor	92
148.	„ „ ceiling	93
149.	Bridging Joists	93
150.	Ceiling „	94
151.	General Remarks respecting Floors	94
152.	Floors Constructed with Short Timbers	95
153.	Floor at Amsterdam constructed without Joists	95

TABLES OF SCANTLINGS OF FLOOR TIMBERS.

TABLE XXIII.	Scantlings of Girders	97
„ XXIV.	„ Binding Joists	98
„ XXV.	„ Bridging „	99
„ XXVI.	„ Ceiling „	100
„ XXVII.	„ Binders, to carry a ceiling	100

SECTION IV.

ON THE CONSTRUCTION OF ROOFS.

ARTICLE		PAGE
154.	Introductory Remarks	101
155.	Pitch of Roofs	102
156.	Weight of Roof Covering	102
157.	Pressure of Wind on a Roof	103
158.	On various Forms of Roofs	103
159.	On Untrussed Roofs	104
160.	V-Roof	104
161.	Ridge Roofs	105
162.	Gothic Collar Roof	105
163.	Curb Roof	106
164.	On Trussed Roofs. King-Post Roof	106
165.	Iron King-Post	107
166.	Queen-Post Roof	107
167.	Roof for span of from 20 to 30 feet	107
168.	„ „ „ 30 „ 46 „	107
169.	„ „ „ 46 „ 60 „	108
170.	„ „ „ 75 „ 90 „	108
171.	„ „ „ 55 „ 65 „	108
172.	„ of Drury Lane Theatre	108
173.	„ „ Basilica of St. Paul at Rome	109
174.	„ „ Theatre D'Argentina at Rome	110
175.	„ at Ancona and Florence	110
176.	„ of Leghorn Cathedral	111
177.	„ „ Academy at Florence	111

ARTICLE		PAGE
178.	Roof of Parkhurst Prison	111
179.	„ „ Christ's Hospital, London	111
180.	„ „ Great Northern Railway Station, London	112
181.	„ „ Store-Room at Bombay	112
182.	„ with Curved Ribs	115
183.	„ „ „ for small spans	116
184.	„ of Riding-house at Moscow	117
185.	„ „ Great Northern Railway Terminus, London	117
186.	De Lorme's System of Curved Ribs	118
187.	On the Thrust of Arched Ribs	119
188.	Collar-Beam Roofs	120
189.	Trussed „ designed by Mr. Price	121
190.	„ „ over Exchange at Genoa	121
191.	„ „ Riding School at Modena	121
192.	„ „ St. Martin's-in-the-Fields, London	122
193.	Roofs over Docks and Slips	122
194.	Hammer-Beam Roofs	123
195.	„ „ over Westminster Hall	124
196.	„ „ „ Hampton Court and Eltham Hall	124
197.	„ „ „ Churches of Norfolk and Suffolk	125
198.	„ „ „ with Collar-Beams over Churches of Norfolk and Suffolk	125
199.	Double Hammer-Beam Roofs over Churches of Norfolk and Suffolk	125
200.	Roof of Manchester Assize Courts	125
201.	Strains on a Hammer-Beam Roof	126

ON PROPORTIONING THE PARTS OF ROOFS.

202.	Introductory Remarks	127
203.	Of King-Posts	127
204.	Of Queen-Posts and Suspending Pieces	128
205.	„ of iron	129
206.	Joint of King-Post with Rafter	129
207.	Of Tie-Beams	129
208.	„ laid on shoes and blocks in walls	130
209.	Of Principal Rafters	131
210.	Of Straining Beams	132
211.	Of Struts and Braces	133
212.	General Remarks	133
213.	Of Purlins	134
214.	Of Common Rafters	134
215.	Of Hipped Roofs	135

TABLES OF SCANTLINGS OF ROOF TIMBERS.

TABLE	XXVIII.	Spans from 20 to 30 feet	137
„	XXIX.	„ 30 „ 46 „	137
„	XXX.	„ 46 „ 60 „	138
„	XXXI.	„ 60 „ 90 „	138
„	XXXII.	„ 55 „ 65 „	139
„	XXXIII.	„ 70 „ 85 „	139

PAGE

TABLE XXXIV. Curved Roofs 20 to 32 feet span 139
„ XXXV. „ 35 „ 100 „ 140
„ XXXVI. Scantlings of Purlins 140
„ XXXVII. „ Common Rafters 141

SECTION V.

ON THE CONSTRUCTION OF DOMES AND SPIRES.

ARTICLE

216. Definitions and Introductory Remarks 142
217. On the Construction of Domes with Horizontal Ties 142
218. „ „ St. Paul's Cathedral, London 143
219. „ „ without Horizontal Ties 143
220. Mathematical Theory of the Thrust of Domes 144
221. Joint of Rupture in Domes of various forms 150
222. On the Construction of Spires... 150

SECTION VI.

ON THE CONSTRUCTION OF PARTITIONS AND FRAME HOUSES.

223. On the Construction of Quarter-Partitions 152
224. Scantling of Timbers for „ 153
225. Partitions without Quartering... 153
226. Weight of Partitions and Floors 153
227. Designs for Trussed Partitions 154
228. Strain on the Timbers of Trussed Partitions 154
229. On the Construction of Frame-Houses 155

SECTION VII.

TEMPORARY STRUCTURES.

ON THE CONSTRUCTION OF CENTRES, SCAFFOLDING, SHORING AND COFFER-DAMS.

CENTRES FOR BRIDGES.

230. Definition and Introductory Remarks 156
231. Pressure of Arch Stones upon Centres 157
232. Rule for „ „ 158
233. Pressure on the Centre increases with the Angle of the Voussoirs 159
234. Formula for the Pressure of Voussoirs 159
235. On Designing Centres 160
236. Centering of Conon and Coldstream Bridges 160
237. „ Neuilly Bridge 161
238. „ Waterloo „ 161

ARTICLE		PAGE
239.	Centering for Bridges of moderate span	161
240.	„ London Bridge	162
241.	On the Construction of Centres	162
242.	On Removing Centres	163
243.	Centering for Chester Bridge	164
244.	On Computing the Strength of Centres	165
245.	Application of the Rule for Computing the Strength of Centres	165
246.	Examples	166

ON THE CONSTRUCTION OF SCAFFOLDING.

247.	Gantries, Nelson Column	167
248.	Staging for the Houses of Parliament	168
249.	„ St. Pancras Station	169

ON SHORING.

250.	On the Erection of Raking Shores, and Needling	170
251.	Computation of the Strains on a Raking Shore	170
252.	Strutting	171

ON THE CONSTRUCTION OF COFFER-DAMS.

253.	Description of a Coffer-Dam	172
254.	Coffer-Dam for Houses of Parliament	172
255.	„ London Bridge	173

SECTION VIII.

ON WOODEN BRIDGES AND VIADUCTS.

256.	Notices of Ancient Bridges built by Romans	174
257.	„ Palladio's Bridge over the Brenta, and one by Morand over the Rhone	174
258.	Bridges built and designed by Palladio	175
259.	„ formed with Curved Ribs	175
260.	American Bridges	175
261.	„ Lattice Bridges	176
262.	„ Frame „	177
263.	„ „ „ with Iron Ties	178
264.	„ Bridges with Arched Ribs	178
265.	Bridge at Trenton, over the Delaware	179
266.	„ Columbia „ Susquehanna	179
267.	„ Philadelphia „ Schuylkill	179
268.	„ Schaffhausen, Switzerland	180
269.	„ Freysingen, Bavaria	180
270.	„ Bamberg and Ettringen, Germany	182
271.	Table of Dimensions of Wiebeking's Bridges	183
272.	„ Spans of Celebrated Bridges	184
273.	On the Design of Wooden Bridges	184
274.	The Width of the Roadway	185
275.	On the Waterway left for the River	185

ARTICLE		PAGE
276.	Table of Velocities of Rivers, according to the nature of the river bottom	186
277.	Formulæ for Breadth and Fall of Waterway	187
278.	Table of Velocities of Principal Rivers	188
279.	Of the Span of the Arches	188
280.	Of the Rise „	189
281.	Proportion of Rise to Span	189
282.	Construction of the Abutments and Piers	191
283.	Computation of the Thrust of a Timber Arch	192
284.	Piers of Stone	193
285.	„ Wood	193
286.	„ Telford's Bridge over the Severn	194
287.	Ice-breakers	194
288.	Construction of the Arches and Timber Frames for Wooden Bridges	195
289.	Bridges with Tie-Beams	195
290.	„ „ Curved Ribs	196
291.	„ „ Framed „	197
292.	„ for Short Spans	198
293.	„ „ „ „ with Curved Ribs	198
294.	„ „ Long „ „ „	199
295.	„ „ Spans above 250 feet	200
296.	Rise of Curve in Ribs for different Spans	200
297.	Of the Roadway	201
298.	On the Scantlings of Bridge Timbers	202
299.	To determine the Strength of Ribs	204
	ON THE CONSTRUCTION OF VIADUCTS.	
300.	Definition and Introductory Remarks	204
301.	Brunel's Viaduct at College Wood, Cornwall	205
302.	„ „ St. Germans „	205
303.	The Elwell Viaduct	205
304.	South Wales Railway Viaduct...	206
305.	Level Crossing Gate	206

SECTION IX.

ON SCARFS, JOINTS, STRAPS, BOLTS, SHOES, AND SOCKETS.

306.	Introductory Remarks	207
307.	On Lengthening Pieces of Timber to Resist Tension	208
308.	Scarfing Timbers	208
309.	On Lengthening Beams to Resist Cross Strains	210
310.	On Building Beams	210
311.	On Lengthening Beams to Resist Compression	211
312.	Of Joints for bearing purposes...	211
313.	„ of Framing...	212
314.	„ of a Post on a Sill	213
315.	„ of Rafters	213
316.	„ „ and Straining Beams	214
317.	Of Suspending Pieces	215
318.	On Joints for Ties and Braces	215

ARTICLE		PAGE
319.	On Connecting the parts of Joints	216
320.	On cast-iron Shoes	216
321.	„ Sockets	219
322.	Strap for King- or Queen-Post	220
323.	„ at foot of Rafter	220
324.	On Preserving Iron from Decay	221
325.	On Iron Bolts	221
326.	„ Nails	221
327.	„ Screws	222
328.	To Preserve Iron Fastenings from Rust	223

SECTION X.

ON THE NATURE AND PROPERTIES OF TIMBER.

329.	Nature of Wood	224
330.	Appearance of the Cross Section of a Tree	224
331.	The Structure of Wood	224
332.	Characters of the different parts of the Trunk of a Tree	225
333.	Mode of Growth in Timber Trees	225
334.	Medullary Rays	226
335.	Alburnum or Sapwood	226
336.	Life of Trees	226
337.	On Felling Timber: Proper Age for Felling	227
338.	Proper Season for Felling	228
339.	Girdling Oak Trees	228
340.	On Seasoning Timber	229
341.	Table of Time required for Seasoning Timber according to Size	231
342.	Water Seasoning	231
343.	On Steaming and Boiling Timber	232
344.	On Smoke-drying, Scorching, and Charring Timber	233
345.	Langton's Method of Seasoning by Extraction of Sap	234
346.	Tables of the Weight of Timber in different States	235
347.	Laws of Seasoning	238
348.	Comparison of Times required to Season and Dry Timber	239
349.	Computation of the Evaporation of Moisture from Wood under Cover	240
350.	Decay of Timber: Effect of continued Dryness	241
351.	Effect of continued Wetness	241
352.	„ alternate Dryness and Moisture	241
353.	„ continued Moisture with Heat	242
354.	Rotting of Timber: Formation of Fungus	244
355.	Decay of Sapwood	244
356.	Decay prevented by constant Wet	244
357.	„ hastened by Warmth and Moisture	245
358.	„ „ Stoves	245
359.	„ „ building Timber into Walls	245
360.	„ „ Painting	246
361.	Prevention of Decay: Proper Seasoning	247
362.	Damp-proof course in Walls	247
363.	Walls to be well dried	247
364.	Plastering to be well dried before fixing Joiner's Work	247

ARTICLE		PAGE
365.	Access of Damp from earth to be prevented under floors	248
366.	Impregnating Timber with Salt	248
367.	„ „ Sulphate of Iron	248
368.	„ „ Lime Water and Sulphuric Acid	249
369.	Action of Quicklime on Timber	249
370.	Kyan's Process for Preserving Timber	249
371.	Tests of Kyan's Process at Woolwich	250
372.	Proof „ being an effectual Preservative	250
373.	Effect „ on Strength of Timber	250
374.	Repairs of Buildings affected with the Rot	251
375.	To Preserve Wood exposed to weather	252
376.	Prevention of Ravages of Worms and Insects	252
377.	Attacks of Animals on Timbers exposed to the Sea	253
378.	Smeaton's Remedy for Preventing Piers being destroyed by Worms	254
379.	Destructive action of Termites	254
380.	Durability of Timber...	255
381.	Timber buried in earth	255
382.	„ „ tombs, and in middle of walls	256
383.	Durability of Framed Timbers...	256
384.	Relative Durability of different kinds of woods	257
385.	„ „ planks after ten years' exposure	258

ON THE STRUCTURE AND CLASSIFICATION OF WOODS.

386.	Appearance of the Cross Section of a Tree	259
387.	Table of the Arrangement of the Species of Woods	260
388.	Cohesive Force of Wood	260
389.	Modulus of Elasticity	261
390.	Hardness of Wood	261
391.	Toughness „	261
392.	Softness, Flexibility, Brittleness	261
393.	Oak as the Standard for comparing other woods	262

DESCRIPTION OF WOODS.

394.	CLASS I.—Wood having large Medullary Rays	262
395.	DIVISION I.—Oak	262
396.	Varieties of Oak	263
397.	DIVISION II.—Beech, Alder, Plane, and Sycamore	268
398.	Beech	268
399.	Alder	269
400.	Plane Tree	270
401.	Sycamore...	270
402.	CLASS II.—Woods without large Medullary Rays...	271
403.	DIVISION I.—Wood having annual ring compact on one side and porous on the other	271
404.	Chestnut	271
405.	Ash	273
406.	Elm	275
407.	Common Acacia	276
408.	DIVISION II.—Wood uniformly Porous	277
409.	Mahogany	277
410.	Walnut	278
411.	Teak	279

ARTICLE		PAGE
412.	Poona	280
413.	African Oak	281
414.	Poplar	283
415.	DIVISION III.—Pores containing resinous matter	284
416.	Cedar of Libanus	284
417.	Red or Yellow Fir	285
418.	White Fir or Deal	287
419.	American Pines, Yellow or Weymouth Pine	289
420.	„ Red Pine	289
421.	„ Pitch Pine...	289
422.	Silver Fir	290
423.	Cluster Pine or Pinaster	290
424.	Larch	290
425.	its Value for Ship-Building	292
426.	„ its Crushing Strength	292
427.	„ its Transverse „	292
428.	Cedar or Juniperus...	294
429.	Cowrie or Cowdie Pine	294

TABLES OF SPECIFIC GRAVITIES AND OTHER PROPERTIES OF TIMBER, ETC.

TABLE XXXVIII.	Properties of different kinds of Timber	295
„ XXXIX.	The Specific Gravity and Weight of a Cubic Foot of different Woods	296
„ XL.	„ „ „ various substances	298

APPENDIX.

SPECIMENS OF VARIOUS ROOFS OF IRON AND STONE ILLUSTRATED BY THIRTEEN PLATES.

Iron Roof over Smithery at Butterley	301
„ for Quay at Glasgow	302
„ „ Messrs. Whitworth at Manchester	302
„ „ Galway Terminus	302
„ „ Abbey Mills Pumping Station	302
„ at Swansea	302
Stone Vaulting of King's College Chapel, Cambridge, and Westminster Abbey	303
„ Description of the Plates	311

ELEMENTARY PRINCIPLES

OF

CARPENTRY.

INTRODUCTION.

ART. 1.—CARPENTRY is the art of combining pieces of timber for the support of any considerable weight or pressure.

The theory of carpentry is founded on two distinct branches of mechanical science, which, says Professor Robison, makes carpentry a *liberal* art, constitutes part of the learning of the ENGINEER, and distinguishes him from the workman; the one informs us how strains are propagated through a system of framing; the other, how to proportion the resistance of its parts, so that all may be sufficiently strong to resist the strains to which they are exposed. The one determines the *stability of position*, the other the *stability of resistance*. Each of these will be considered in the most simple manner the subject admits of, with the addition of rules and practical remarks.

Timber is wrought into various forms according to the principal of geometry; and these forms are to be preserved in their original shape only by adjusting the stress and strain according to the laws of mechanics. Hence the importance of studying both these sciences is evident, and particularly the latter; for unless the stress and strain be accurately adjusted, the most careful attention to geometrical rules, and the most skilful workmanship, will be exerted in vain. If, for instance, the centre of an arch were to be drawn and worked ever so truly to the curve required, what would it avail if the centre changed its form with every course of stone laid upon it? And it must be remarked, that this is not an imaginary case, but one that has frequently happened; and not only to men ignorant of mechanics, but also to some of the most celebrated engineers that France ever produced.

The engineers of our own country have been more successful, having succeeded in gradually introducing a better principle of constructing centres than our neighbours. The greatest defect of the English centres is now an excess of strength, which on principles of economy it would be desirable to avoid in erections for temporary purposes.

2.—The stability of position is determined by that part of mechanical science which treats of the pressure and equilibrium of bodies. Its application to the carpenter's purposes has

been effected in the most clear, simple, and useful manner, by Professor Robison and other more recent writers, to whom we are indebted for suggesting the mode of treating the first section. But though Professor Robison treated the subject in the most popular and simple manner, the greater part of the principles and the rules of his articles had been investigated before by Emerson in his *Mechanics*, *Fluxions*, *Algebra*, and *Miscellanies*.

3.—The stability of resistance is determined by that part of mechanical science which treats of the resistance of solid bodies. And notwithstanding the valuable accessions which the theory of carpentry had received from the labours of Emerson, and the excellent articles by Professor Robison, the carpenter was not able to reap much benefit from them till the importance of the laws of flexure was more fully developed by Dr. Thomas Young, in his *Lectures on Natural Philosophy*. It is true that some of the continental mathematicians had been occupied before in researches relative to the flexure of columns; but their method is embarrassed with so many difficulties, and so intricate in itself, that human care was scarcely capable of preventing errors from creeping into their investigations.

By adopting a more simple and elegant method, Dr. Young has established many important principles relating to the flexure of bodies, and determined that principle which limits the stress to which materials should be exposed. But still something more simple appeared to be wanted for the carpenter's purposes; a work which, without aiming at refined mathematical demonstration, should indicate the sources from whence its rules may be derived, and adapt them to practice. Such a work it is hoped this will be found; at the same time, from its being confined to subjects connected with carpentry, the same information may be gained at less expense than from books where the subject of carpentry is only treated of in as far as it is connected with philosophy and science.

SECTION I.

ON THE EQUILIBRIUM AND PRESSURE OF BEAMS, OR THE STABILITY POSITION.

4.—It is through a knowledge of the composition and resolution of forces alone that the carpenter can expect to arrive at excellence in the art of designing frames of timber, for the purposes of building, for machines, and other uses; as without this knowledge it would be impossible for him to understand clearly what is to be aimed at in such designs; or even to know whether a design of his own would answer its intended purpose or not.

The first step towards obtaining this knowledge, is that of acquiring just notions of the action of forces.

By the action of gravitation, a heavy body always exerts a force equal to its own weight in a vertical direction; and would always descend in a vertical line, if not prevented from following that direction by some other force: and its force is always the same as if it were collected in, and acting in, that line.

But when a heavy body W (*Plate* I., *fig.* 1) is sustained by two inclined beams, AC and BC, its effects on these beams depend on their position: the further the ends A and B are set apart, the greater will be the strains on the beams; and the nearer A and B are together, the less will be the strains. Here it is obvious that the weight resolves itself into two forces, one in the direction of each beam, producing a corresponding reaction of the supports at A and B.

We may now proceed to explain what is meant by the composition and resolution of forces.

ON THE COMPOSITION AND RESOLUTION OF FORCES.

5.—The *Resolution of forces* consists in finding two or more forces, which, acting in any different directions, shall balance or have the same effect as any given single force. Thus the weight W (*fig.* 1) might be sustained by a vertical force in the direction of *c*C equal to the weight; and this vertical force, it is obvious, may be resolved into two forces, in the directions of the beams, that would produce exactly the same effect as the vertical force C*c*; and the two forces into which W is resolved are called the *components* of that force.

The *Composition of forces* consists in finding one force that shall produce the same effect as two or more forces acting in different directions. This is nothing more than the reverse of the resolution of forces, and may be accomplished in a similar manner. The single force to which a number of forces are equivalent is called their *resultant.*

If a vertical line C*c* (*fig.* 1) be drawn through the centre of the weight, and *a c* be drawn

parallel to the beam AC; also *b c* parallel to BC; then C*c* is the diagonal of the parallelogram C *a c b*, and the relations between the weight and the pressures will be found by the following proportions:—

As the line C*c*,
Is to the line C*b*;
So is the weight W,
To the pressure in the direction of the beam AC.

Also, As the line C*c*,
Is to the line C*a*;
So is the weight W,
To the pressure in the direction of the beam CB.

To those who are acquainted with the principles of mechanics, the truth of the principle from which these proportions are derived requires no illustration; but such as have not had the advantage of that branch of learning, may, by having recourse to the following simple experiment, not only satisfy themselves of its truth, but also render themselves more familiar with the nature of forces.*

6.—Let a thread or fine line be passed over the pulleys B and C (*fig.* 2), and let a known weight be attached to each end of the line, as at *b* and *c*; also let another thread be knotted to the first one at any point A, and attach a known weight to the end W. Then, if the sum of the weights *b* and *c* be greater than the single weight W, there is a certain position in which the assemblage will be at rest; and if it be deranged by pulling at any of the weights it will return of itself to the same position when left at liberty. Therefore, in that position, and in that position only, the weights will balance one another, or be in equilibrio. Now if the positions of the threads, when the weights balance each other, were drawn upon paper; and, from a scale of equal parts, AF were made equal to the number of pounds in the weight W, and the line BA were continued to E, and the line FE drawn parallel to AC; then FE measured by the same scale of equal parts would show the number of pounds' weight of the body *c*; also the measure of the line AE would be equal to the number of pounds' weight in the body *b*.

If the three weights be equal, then the three lines, AF, FE, and AE, will be equal, and the angles formed by the threads round the knot will be equal.

7.—And, universally, whenever the directions of three forces are in the same plane, and meet in a point, and are in equilibrium, those forces will be represented in magnitude by the three sides of a triangle drawn parallel to the directions of the forces.

Consequently, if a body be kept at rest by three forces, and any two of them be represented in magnitude and direction by two sides of a triangle, the third side taken in order will represent the magnitude and direction of the other force.

8.—Also, because the sides of triangles are as the *sines* of the opposite angles, it follows, that when three forces keep a body in equilibrium, each force is proportional to the *sine* of the angle made by the directions of the other two. Thus, the weight W (*fig.* 2) is to the weight *b*, as the *sine* of the angle AEF to the *sine* of the angle AFE, &c.

* The reader who wishes to have more scientific information on the subject may refer to Gregory's *Mathematics for Practical Men*, or Baker's *Principles and Practice of Statics and Dynamics* (Crosby Lockwood & Co.); also to Goodeve's *Principles of Mechanics*.

It may, however, be observed, that the designs of framing are drawn on paper to a scale; hence the proportions of the forces may always be obtained immediately from the figure without the trouble of calculation, and the values of the forces so obtained will be accurate enough for any practical purpose. This method is therefore adopted, whenever it is found most convenient, in the following pages.

9.—Again, considering the combination of force in *fig.* 1; let the vertical line C*c* be drawn, and by a scale of equal parts make C*c* equal to the number of pounds, hundred-weights, or tons, contained in the weight W. Then draw *c b* parallel to BC, and *c a* parallel to AC; and C*b*, measured from the same scale, will show the number of pounds, hundred-weights, or tons, by which the beam CA is strained; and in like manner, C*a* will be the measure of the strain on the beam CB, in pounds, hundred-weights, or tons. The pressure is not altered by making the beams longer or shorter, so long as their positions remain the same; but the power of a beam to resist pressure is much lessened by increasing its length: the effect of this power, however, must be treated of in another part of this work. (See Section II., Art. 125.) Only here it may be remarked, that when one beam is much longer than another, in a system of framing, the position of the line of direction of the weight will vary a little from its intended position; because a beam of 10 feet in length will compress twice as much as one that is only 5 feet long, which must cause a corresponding change in the directions of the forces. Also, if a beam that has to sustain a pressure in the direction of its length be joined in several places, it will yield more than one of the same length that has no other joints than those at its ends; and the yielding will be nearly in proportion to the number of joints, supposing them all to be equally well made; for it is impossible to make a joint that will not yield in some degree.

Changes of form in an assemblage or system of framing almost always increase the effect of the weight, and often produce cross-strains that are attended with the worst consequences, when such changes are not foreseen, and provided for by making each compressed member a little longer, and each stretched member a little shorter, than in the drawn design; the drawing being always to be regarded as representing the *ultimate* form of the structure, after all yielding or change from compression and stretching shall have been completed.

10.—The place of either of the beams may be supplied by two other beams applied in the same plane, and jointly bearing the same pressure as the beam they replace. Hence, by taking the pressure in the direction of the single beam as the force to be sustained, the pressures in the directions of the two which replace it, may be found by constructing the triangle of forces as already described; and, in this manner, the supports of a load may be resolved into any number of parts acting in different directions, but in directions meeting in the same point: also the effect on each may be measured by resolving any single pressure into two parts in the same plane.

11.—If the feet of three or more beams be placed in a circle, and inclined to a verticle line passing through its centre, so as to support a tower or other load, when the beams are equidistant the stress will be equally divided among the beams; and if the load be divided by half the number of beams, and this be considered the load supported by two beams, drawn opposite to one another at the same inclination, the stress in the direction of the beams may be found. It is not possible for the beams to be opposite when the number is odd, but the above construction gives the stress whether their actual places be opposite or not.

ON THE EFFECT OF POSITION.

12.—If the position of the beam CB (*fig.* 1) were changed to that shown by the dotted lines CE, the magnitude of the strain would be prodigiously increased on both beams. By drawing lines parallel to the beams in this position, expressing the weight by the line C*c* the same as before, the pressure on the beam in the position CE will now be measured by the line C*d* instead of C*a*, being obviously much increased; while the strain on the beam CA will be nearly doubled, being represented by the line C*e*.

Hence it appears that enormous strains may be produced by a comparatively small weight, merely by altering the position of the supports. The reader will do well to consider these changes with attention, and to draw figures in different positions, estimating the pressures according to each position; which will render his mind familiar with the subject; and enable him, in practice, to form accurate notions of the magnitudes of pressures, without the labour of calculation.

TO MEASURE THE STRAINS IN A FRAMED TRUSS.

13.—If, instead of placing the weight on the point where the beams meet, the beams were framed into a piece of timber CE (*fig.* 3), and the weight W suspended at E, the pressures would still be propagated in the same manner, and would be found by the same means; that is, if C*c* represent the weight, C*b* will be the pressure in the direction of the beam CA, and C*a* the pressure in the direction of the beam CB.

In this case CE performs the office of the king-post in a roof, CA and CB representing the principal rafters.

14.—Hitherto the ends of the beams, marked A and B, in *figs.* 1 and 3, have been considered to be supported by an immoveable obstacle; but when there are no such obstacles, they obviously have a tendency to spread; therefore they might be connected by a rope, a rod of iron, or another beam, which would answer a purpose nearly similar to the tie-beam of a roof. It is not quite the same, because in modern buildings a tie-beam has in general to support a ceiling, which a rope or rod of iron would not be sufficient to do.

Let *fig.* 4 represent an assemblage of this kind, where AB is the tie to prevent the lower ends of the beam AC and CB from spreading. This form is similar to the truss of a roof.

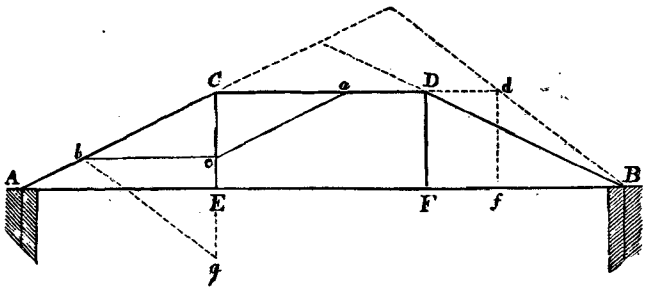
The strain on the tie AB may be found by drawing *b f* parallel to the tie AB; then, if C*b* represent the pounds or tons with which AC is pressed (found by Art. 9), *b f*, measured from the same scale of equal parts, will be equal to the strain in the direction of the length of the beam or tie AB in pounds or tons. And the equal and opposite strain at B will be measured by *e a*, which is equal to *b f*.

If the load, and therefore the king-post, be in the middle of the span, the vertical pressures on the walls will be equal; but when out of the middle, the vertical pressures will be unequal, and the point *f* divides the line C*c* into two parts, which are proportional to the pressures; C*f* being the vertical pressure on the wall at A, and *f c* or C*e* the vertical pressure on it at B, when C*c* is the whole weight.

15.—Where there is a want of height, or where the weight is distributed over a considerable part of the span, the truss may be of the form shown in the annexed diagram (*fig.* 1). The

stress at C and D should be equal when the parts of the truss are alike; but should the centre of the load not correspond with the centre of the opening, then, from a point in the vertical line corresponding to the centre of the load, draw lines to the supporting points in a convenient direction for the supports, and C*d* will be the length of the beam to insert between the upright pieces CE, *d f*, commonly called queen-posts.

FIG. 1.

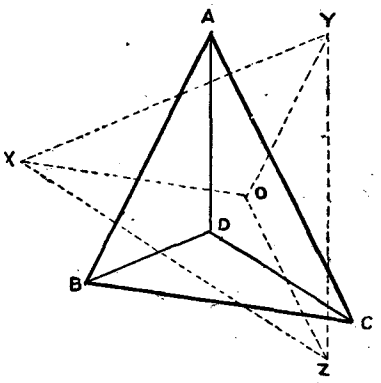


In either case the stress on each piece may be measured by setting off C*c* equal to the pressure on the point C, and from *c* draw lines parallel to the pieces AC and CD; then C*b* represents the stress along AC, and C*a* the stress along CD. If the parts of the truss be dissimilar, the whole weight should be represented by C*g*; and draw *b g* parallel to *d* B; the line *b g* then represents the stress along *d* B, the other forces being as before.

16.—The method of diagrams introduced by the late Professor Clerk Maxwell enables us to measure off with accuracy all the various strains to which the several parts of a piece of framework are subjected. The principle involved in this method is as follows:—

In the diagram (*fig.* 2) let ABC be a triangular piece of framework jointed at A, B, and C, and kept in equilibrium by the action of three forces acting at the joints. Since there is equilibrium the directions of these forces must meet at some point, D, and must also be proportional to the sides of a triangle which are respectively parallel to the lines AD, BD, CD. Let XYZ be such a triangle. Then to find the stresses in AB, BC, CD, arising from the forces, draw lines from the points X, Y, Z, parallel respectively to the sides of the triangle ABC; these will meet in a point O, and the line XO will represent the stress in BC; YO that in AB; ZO that in AC; to the same scale as that on which the sides of the triangle XYZ, represent the original forces acting at the joints A, B, C. The figure ABC is called the "frame diagram," and the figure XYZ the "stress diagram." The lines which in the former make a closed polygon are represented in the latter by lines meeting in a point, and *vice versâ*; so that they may be called *reciprocal figures.*

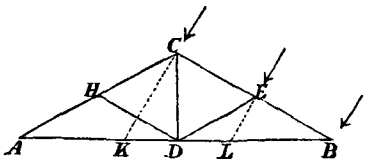
FIG. 2.



17.—The following example will show the application of this method to a king-post roof, and also how the strain produced by the pressure of the wind acting on one side only of the roof at a time can be estimated.

Let the diagram (*fig.* 3) represent the truss having a span of 20 feet, the rafters being inclined to the tie-beam at 30°, and the trusses supposed 10 feet from centre to centre; the purlins will throw the weight on the points A, H, C, E, and B. Assume that 20 lbs. per square foot, measured on the slope, is the weight of the roof timbers (except tie-beam and ceiling) together with the covering and snow; then 4,600 lbs. is the weight borne by each truss; the weight of the tie-beam and ceiling 2,400 lbs. Let the force of the wind be 40 lbs. per foot acting perpendicularly to the slope of the rafters on one side only; this will amount to 4,600 lbs. uniformly distributed over one side of the roof and at right angles thereto. Now, when a continuous beam is uniformly loaded and supported at the centre and two ends, it is generally reckoned, either that $\frac{1}{4}$ the load is borne at each end and $\frac{1}{2}$ at the middle, or that $\frac{3}{16}$ of the load is borne at each end and $\frac{5}{8}$ths at the middle. Adopting the latter hypothesis, we find that the loads at A and B are each $\frac{3}{32} \times 4{,}600 = 430$ lbs.; at C, $\frac{6}{32} \times 4{,}600 = 860$ lbs.; at E and H, $\frac{5}{16} \times 4{,}600 = 1{,}440$ lbs. Also the weight of tie-beam and ceiling produces a load of $\frac{3}{16} \times 2{,}400 = 450$ lbs. at A and B, and of $\frac{5}{8} \times 2{,}400 = 1{,}500$ lbs. at D. The force of the wind on the right hand side produces at B and C a pressure of $\frac{3}{16} \times 4{,}600 = 860$ lbs., and at E of $\frac{5}{8} \times 4{,}600 = 2{,}880$ lbs.

FIG. 3.

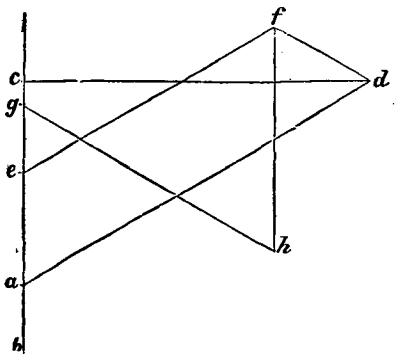


We have now to draw two stress diagrams, one showing the stresses arising from the vertical forces, and the other those produced by the pressure of the wind acting at right angles to one side of the roof.

Half the total weight of the roof is of course borne at each end A and B, and amounts to 3,500 lbs., which is the reaction at A and B.

To construct the diagram (*fig.* 4) for vertical forces, draw a vertical line *c b*, and measure *a b* representing on any scale 430 lbs., the pressure at A or B; take *b c* equal to 3,500 on the same scale; draw *c d* parallel to AB, and *a d* parallel to AC. Measure *a e* equal to 1,440 lbs., the vertical pressure at E or H, draw *e f* parallel to AC, and *d f* parallel to DH. Take *e g* equal to 860 lbs., the load at C, and draw *g h* parallel to DH. Then *c d*, *d a* represent in direction and magnitude the stresses in AD, AH respectively, the former in tension and the latter in compression; *d f* and *f e*, those in HD, HC, both in compression; *f h*, the tension in the king-post. Measuring these lines by the scale, we find *c d* = 4,500 lbs. the tension in AB; *d a* = 5,250 lbs. the compression in AH or BE; *d f* = 1,400 lbs. the compression in HD or ED; *f e* = 3,800 lbs. the compression in HC or EC; *f h* = 2,900 lbs., the tension in the king-post CD.

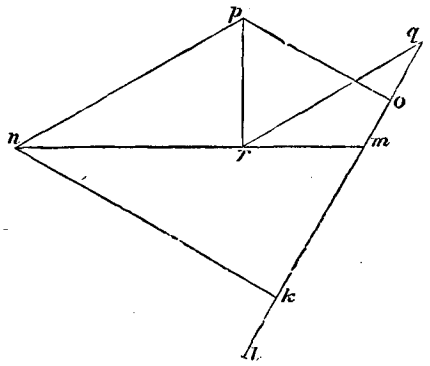
FIG. 4.



We have now to find the stresses arising from the wind acting in the direction of the arrows at B, E, and C, at right angles to BC. The pressure at C is 860 lbs., and

produces a reaction at B equal to $860 \times \frac{AK}{AB}$, or 290 lbs.; also a reaction at A of $860 \times \frac{BK}{BA}$, or 570 lbs. The pressure at E is 2,880 lbs., and produces a reaction at B of 2,880 lbs. $\times \frac{AL}{AB}$, or 1,970 lbs.; and a reaction at A of $2,880 \times \frac{BL}{AB}$, or 970 lbs. Therefore, the total reaction at B is 860 + 290 + 1,900, or 3,050 lbs.; and at A it is 570 + 970, or 1,540 lbs. Draw a line *q l* (*fig.* 5) parallel to CK, and take *k l* to represent 860 lbs., *l m* to represent, on the same scale, 3,050 lbs.; draw *m n* parallel to AB, and *k n* to BC; then *m n* represents the tensile strain in AB, *nk* the compressive strain in BE. Take *k o* equal to 2,880 lbs., and draw *o p* parallel to EC, *p n* parallel to ED; then *o p* represents the compression produced by the force of the wind in EC, and *p n* that in ED. Draw the vertical *p r*, which is the strain in the king-post; and draw *r q* parallel to AC, which is the compression produced in that rafter. Measuring by scale, we find *m n* is 4,400 lbs., the tension in the tie-beam; *n k* is 3,800 lbs., the compression in BE; *o p* is 2,150 lbs., the compression in EC; *p n* is 3,330 lbs., the compression in ED; *p r* is 1,650 lbs., the tension in the king-post CD; *r p* is 2,660 lbs., the compression in AC.

FIG. 5.



Collecting the strains obtained by the two diagrams, we have—

Tension in tie-beam	=	4,500	+ 4,400	= 8,900 lbs.
„ „ king-post	=	2,900	+ 1,650	= 4,550 „
Compression in rafter	=	5,250	+ 3,800	= 9,050 „
„ „ strut	=	1,400	+ 3,330	= 4,730 „

We can now, by applying the rules given in Section II., find the scantlings required in the case before us. Suppose the framing to be of Memel fir, the safe tensile strain of which is 1,200 lbs. per square inch, then the tie-beam need only have a transverse section of $7\frac{1}{2}$ square inches, and the king-post of $3\frac{3}{4}$ square inches; as, however, each half of the tie-beam has to carry a distributed load of 1,200 lbs., the tie-beam, if made 7 inches deep, must be 2 inches thick. To find the strength of the rafters and struts, we must consider them as long pillars, and use the formula (Art. 128)—

$$W = 2,240 \times \frac{d^4}{l^2},$$

which is the safe load when *d* is the diameter in inches and *l* the length in feet. Putting $l = 6$ feet, we find the rafters must have a scantling of $3\frac{3}{4}$ inches square, and the struts about $3\frac{1}{4}$ inches square. In these dimensions, however, no allowance is made for cutting away portions of the timber for mortises or for defective portions of the wood.

Taking these into consideration we have the following scantlings:—Tie-beam 7 × 3, king-post $2\frac{1}{2} \times 3$, rafters $4\frac{1}{2} \times 3$, braces $3\frac{1}{2} \times 3$.

ON FRAMED LEVERS.

18.—Let *fig.* 4, *Plate* I., be inverted, and supported at C, as represented in *fig.* 5; and a weight hung at each end, so as to balance one another; then the proportion of the strains would remain precisely the same: and it shows how a powerful lever may be framed, and also makes us acquainted with the nature of the strains produced in a solid beam, when it performs the office of a lever. The tie AB is in a state of tension, the beams AC and BC are compressed: in a solid beam the same thing takes place; the side next the support is always compressed, and the opposite side is always in a state of tension. Thus we see the same general principle regulates the equilibrium of matter in all cases, and that all forces act by the same laws.

It may be observed, that when the frame is inverted, as in *fig.* 5, and the tie AB is perfectly straight, there is no strain on the piece CE. But if the tie were of the form shown by the dotted line A*g*B, then the piece *g*EC would be compressed; and, on the contrary, if the tie were of the form represented by the dotted line A*h*B, the piece *h*C would be in a state of tension, or drawn in direction of its length. It is the same with a solid beam; as when it becomes bent in any considerable degree new forces are called into action, and it always bends considerably before breaking; consequently, rules that do not include the effect of the forces that are brought into action, by the bending of a beam, cannot perfectly agree with experiments. The investigation of the stiffness of beams, which is the most useful to the carpenter, being confined to the first degrees of flexure, is not liable to this objection. (See Section II.)

Framed levers have been formed in various ways. *Fig.* 6 shows one constructed with a continued tie bar ACDB, kept at a distance from the centre by two struts; and the construction employed in *fig.* 7 is similar in principle; these were used for the levers of single-acting steam-engines.

FIG. 6.

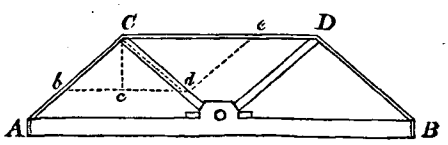
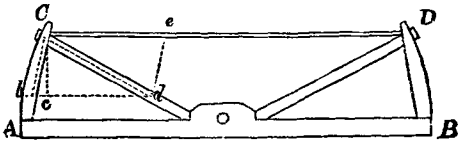


FIG. 7.



If C*c* be the weight to be raised by the end A of either beam, we have C*b* for the stress on AC; C*e* for that on CD; C*d* for that on the strut; and *b c* for the stress on AB: the two former are tensile, the latter two are compressive. In the lever of a double-acting engine the same parts are alternately extended and compressed, and consequently must be adapted to resist either strain.

EFFECT OF POSITION FURTHER CONSIDERED.

19.—To take another example: let *fig.* 6, *Plate* I., represent a frame fixed against a wall, and let the weight be suspended from the point C, where the beams CA and CB join. In this assemblage the beam AC will be stretched, and the beam CB will be compressed; or, in other words, AC will act as a tie, and CB as a strut.

To estimate the amount of these forces, draw the line C*c* in the direction in which the weight would move if left at liberty, that is, in a vertical direction; then, from a scale of equal parts, set off C*c* equal to the weight in pounds; from *c*, draw *c b* parallel to CA, and C*b* will represent the force pressing on the beam CB; also, *c b* or C*a* will represent that stretching CA, which being each measured by the scale will give the values of these strains in pounds.

If the position of the beams in *fig.* 6 were changed to that shown in *fig.* 7, the beam BC would still act as a strut; that is, the weight would have a tendency to compress it: this is evident, because, notwithstanding its inclined position, its place could not be supplied by a rope, which would be the case if it were only stretched.

In *fig.* 8, AC is in a state of tension, and its place might be supplied by a rope, though it appears from its position to act as a strut. In either of these cases the magnitudes of the strains are to be estimated as in *fig.* 6. As the line representing the weight is the same in each, by comparing these figures it will be seen how much the pressures are increased by altering the position of the beams. The strains are obviously the least in the arrangement in *fig.* 6. Also, referring to the frame *fig.* 5, it will be found that a tie following the line A*g*B will support the weights with less strain on the parts of the truss than the straight tie AB; and the higher the point *g* is, the less the strain will be: this is equally true of the truss when inverted.

20.—The last three figures are each similar to the jib of a crane, but the strain upon the jib of a crane is very different: this difference will now be explained, and at the same time some principles that ought to be attended to in the construction of jibs will be pointed out.

Let DCE (*fig.* 9) represent the rope by which the weight is raised passing over a pulley at C; it is clear that the strain in the direction CD is equal to strain in the direction CE; but in each of the cases represented in *figs.* 6, 7, and 8, the strain was in the direction CE only.

Now if we make CE equal to CD; and draw BE parallel to DC, cutting the line DB in B; then, joining BC, we have a direction of a beam that would sustain the forces in the directions DC and EC: and the beam placed in the direction BC would sustain the whole effect of the strains with the least force possible; only requiring a piece AC to steady it.

But when the beam BC is placed in any other position than that found by constructing a parallelogram of equal sides on the directions of the ropes, the effect of the straining forces will be increased, and will vary according to the position of the sustaining beams. For example: let the beam BC be removed to the position shown by the dotted lines B_1C. Then both AC and B_1C will be in a state of compression. Let the vertical C*a* represent the weight

W; then C*b* will represent the force in the direction of the beam in the position CB_1; and *b c*, that compressing the beam AC; from which the equivalents of these forces in pounds or other weights may be ascertained.

Again: suppose the beam BC to be removed to the position shown by the dotted lines B_2C, instead of B_1C; then it would be compressed, and the strain nearly doubled; while the beam AC would be in a state of tension, under a considerable strain. This is of all others the most defective form for a crane jib; yet it is that which is most commonly used. When C*a* represents the weight W, C*e* represents the pressure on the beam B_2C; and *c e* the tension of the beam AC; and being compared with the same line to represent the weight, in each case we see how devoid of principle the usual methods of construction are, as well as the obvious means of improvement.

21.—The beam BC, in the jib of a crane, is called the *spur;* and its position, so that it shall be the best adapted for the purpose, appears to be a little below the diagonal of a parallelogram of equal sides, constructed on the directions of the ropes. This diagonal may be found as follows: Let DF be the shaft (*fig.* 10, *Plate* II.), and DC, CE, the directions of the ropes for raising the weights. Make CA equal to CG; and draw BG parallel to AC, and AB parallel to CG; then join CB, and it will be the diagonal required, bisecting the angle DCE. Then, placing the foot of the spur a little lower than the point F, where the diagonal cuts the line of the shaft, this will cause both the spur and head-piece to be compressed, and produces the strongest arrangement, and one that will move more steadily than any other.

It is scarcely necessary to state, that in all these cases the beams have been supposed to be capable of motion at the joints, or points of connection; as all the firmness that can be given at the joints is so very small in heavy framing, that its effect, in all cases where calculation is necessary, may be left out of the question. The methods of connecting or joining framing will be considered in a separate section. (See Section IX.)

TO DISTINGUISH TIES FROM STRUTS.

22.—It is necessary, in designing the construction, as well as in estimating the strength of framing, that we should be able to distinguish the struts from the ties; that is, to ascertain which of the beams are compressed, and which of them are stretched; for ties must be either continuous or connected by straps, but struts may be in short lengths. By attending to the following considerations, this may be easily determined. From the point on which the straining force acts, draw a line in the direction that the force would move in if the framing were removed. Then when this line falls within the angle formed by the pieces strained, both pieces are compressed; but when it falls within the angle formed by producing the directions of the sustaining pieces, then both the pieces are in a state of tension.

The following method is a more general one, and includes the case just stated. Let a parallelogram be constructed, on the direction of the straining force as a diagonal; the sides of the parallelogram being parallel to the sustaining forces; then let the other diagonal of the parallelogram be drawn; and parallel to it, draw a line through the point where the directions of the forces meet. Consider towards which side of this line the straining force would move if

left at liberty; and all supports on that side will be in a state of compression, and all those on the other side will be in a state of tension.

The same thing would be true of a plane passing through the point where the forces meet, when three or more forces meet that are not in the same plane; but such cases are of rare occurrence; therefore, we need only consider the examples in *figs.* 3, 6, 7, and 8, *Plate* I., which will enable us to apply the method to all cases where the sustaining forces are in the same plane.

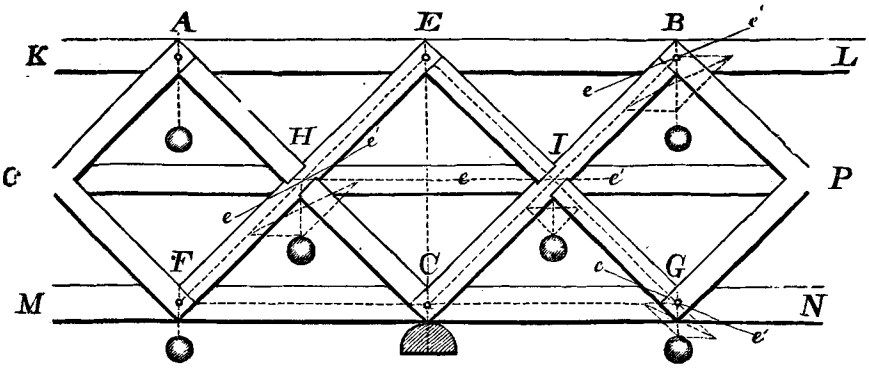
In *figs.* 3, 6, 7, and 8, *Plate* I., C*c* is the direction of the straining force, on which as a diagonal the parallelogram C*bca* is drawn, the sides of it being parallel to the resisting or sustaining beams: join *b a*, and draw the dotted line *e é* parallel to *b a* in each figure; then in *fig.* 3, the straining force would move towards E, if left at liberty; therefore both the beams are compressed, being both on that side of the line *e é*.

In *figs.* 6, 7, and 8, only the lower sustaining beams are compressed; the upper ones are extended: and if the line *e é* were drawn to *fig.* 2, it would show that both the supports are in a state of tension.

23.—The rule applies also to the projections of the directions of the forces when they are similarly disposed in respect to the plane of projection: hence, it is applicable to the framing of ships, with as much facility as to a frame lying all in the same plane. The chord lines of the curved timbers must be considered as their directions; and, as a stress in the direction of the chord line of a curved timber produces an effect similar to a cross strain, the strength (Art. 130) and connections (Art. 309) must be formed accordingly.

In rectilineal framing it is, however, important to distinguish ties from struts in order that the connection of the ties may be preserved; and we will now show how the rule may be applied to this purpose. It is first to be remarked, that no change of construction will alter the operation of the forces, except it renders the parts incapable of resisting the force, which of course must then be sustained by some other part. In the annexed diagram (*fig.* 8),

FIG. 8.



commencing at G, the load is sustained by EG and CG; and constructing the parallelogram, and drawing *e é* through G, we find that CG is compressed and EG extended: hence the latter ought to have been continuous, as the corresponding one FE is on the other side of the support.

Also the weight at I is sustained by EI and CI: find *e é* through I, and it appears that the former is extended and the latter compressed; and in like manner we find that of the supports of B, the one EB is extended, and the other IB is compressed. A similar examination of the other side would give similar results; hence, we find that KL resists tension; MN resists compression; EG and EF resist tension; and it may further be proved that all braces parallel to these must also resist tension; also, AC and BC, and all struts parallel to them, must resist compression. The middle piece OP will not be strained at all as long as the others are perfect: it is in the neutral line between the tensile and compressive strains, and on the failure of the upper tie it would be extended, as is shown at the joint H: and for a moment it seems that the upper tie might be removed, as a bridge projector once proposed; but on further examination it appears this cannot be done without a reduction of half the strength. If the lower piece were removed, then OP would have to resist compression, and except for purposes of connection the middle piece is a useless addition.

TO FIND THE RESULTANT OF A SYSTEM OF FORCES.

24.—As the strain upon a piece of framing is often produced by two or more forces, acting in different directions, of which the crane is an instance, the means of finding a force and its direction, that would be equal in effect to two or more forces, may be next considered a little more attentively. In all cases where the strain is produced by the action of several forces meeting in one point, these forces must be reduced to a single force, capable of producing the same effect; otherwise it will not be possible to determine the strain upon the supports.

A force capable of producing the same effect as two or more forces, is called the *resultant* of those forces.

Let AC represent the magnitude and direction of a force, acting on the body C (*Plate* II., *fig.* 11), and BC the magnitude and direction of another force also acting on the body C. Then to find the resultant, draw *b*B parallel to AC; A*b* parallel to BC; join *b*C, which represents the resultant required. The lines connecting the points A, C, B, *b*, form a parallelogram, of which *b*C is the diagonal; and whenever two meeting sides of a parallelogram are parallel to the directions, and proportional to the energies of two forces, the diagonal meeting them both at the same point will represent the direction and energy of a force that would produce the same effect. A parallelogram constructed in this manner is called a *parallelogram of forces.*

Also, if the force *b*C were to act in the opposite direction, that is, from *a* towards C, it would retain the two forces AC and BC in equilibrium, these acting from A and B towards C; but two forces only can never be in equilibrium, unless their directions be exactly opposite, and the forces equal; and the direction they would move in when not exactly opposite is shown by producing the diagonal of the parallelogram drawn on their directions. Thus C*a* (*fig.* 11, *Plate* II.) is the diagonal produced, and consequently the direction in which the forces AC and BC would tend to cause the body C to move.

One of these forces may be the weight of a structure, of which the direction is vertical, the other force the action of the wind upon it, which is horizontal: the resultant shows the direction and intensity of both the forces acting together; the pressure of the wind on a

surface perpendicular to its direction, has been observed as high as forty pounds on a square foot, which is equivalent to a velocity of ninety miles an hour.

25.—Let it be required to find the resultant of three forces pressing on the point C, of which the magnitudes and directions are represented by the lines AC, BC, and DC (*fig.* 12, *Plate* II.). In the first place complete the parallelogram BCD*b*, as in the preceding example; from which we find *b*C to be the resultant of the two forces BC and DC. Then consider *b*C and AC as two forces, and complete the parallelogram A*ab*C, and *a*C is the resultant required; that is, a force, the magnitude and direction of which is represented by *a*C, would produce the same effect in moving the point C as the three forces AC, BC, and DC. Also, a force equal to *a*C, and opposite, would keep these three forces in equilibrium.

By pursuing the same method of reduction, the resultant of any number of forces acting in any directions tending to one point may be found; but when the forces are in the same plane the same thing may be effected more simply as follows:—

Let AC, BC, and DC, *fig.* 13, be the lines representing in magnitude and direction three forces which act on the point C; beginning at any force, as at B, make B*a* parallel and equal to the next force DC; and then make *a d* parallel and equal to the other force AC; draw the line *d*C, and it is the resultant of the three forces.

The figure B*ad*C is called the *polygon of forces*, and the number of its sides will always be one more than the number of the forces.

If on a plane coinciding with the direction of a force to be sustained, the directions and magnitudes of the sustaining forces be projected, the intensity of the resultant, that is, of the force that can be sustained, may be determined by the preceding method, from the projections of the sustaining forces.

26.—When the strain is produced by a single force, it is sometimes useful to know its effect in a particular direction, in order to apply an equivalent support in that direction. Thus, when a force acts obliquely against the plane surface of an immoveable obstacle, the force will have a tendency to slide along the plane; because two forces cannot sustain each other unless they be equal and opposite. Let a force, represented in magnitude and direction by the line AC, *fig.* 14, act obliquely upon the even surface of a plane CB; it is evident that only part of this force will be exerted in a direction perpendicular to the plane, and this part will be represented by the line AB, drawn perpendicular to the plane; and then, CB will represent the force that would prevent it sliding along the plane.

When two pieces of timber are joined obliquely, the pressure on the different parts of the joint may be ascertained by this method; for example: let BD, *fig.* 15, represent the end of a tie-beam, and AC the principal rafter; the force in the direction of the rafter being represented by AC. Then AB, being perpendicular to the part C*a* of the joint, will represent the pressure upon it, and the pressure on the part C*d* will be represented by CB; consequently CB will be the measure of the force tending to splinter off the part D. (See Section IX., on Joints.)

We cannot often oppose a force by one directly opposite, but we can generally find two forces that will answer the purpose; and by constituting a triangle on their directions, and that of the force to be supported, their proportions can always be ascertained. This principle is the most important one in the theory of Carpentry.

27.—If a series of equal ribs be disposed in a circle at the base, and meet either in a point.

or in another circle smaller than the base, then the effort of any rib to resist a straining force parallel to the base will be the strength of the rib multiplied by the *cosine* of the angle comprehended between the plane of the rib and the plane of the direction of the straining force. Hence, where a series of equal ribs are disposed at equal distances in this manner, the effect of any number of them to resist a force parallel to the base may be found by summing the cosines of the angles formed by the ribs. Let $4\ \alpha$ be the angle subtended by the arc occupied by the ribs, the direction of the straining force being supposed to pass through the middle of it, and to coincide with one of the ribs; and put $\beta =$ the angle subtended by the arc comprehended between two ribs, and R equal the resisting force of each rib: then

$$2\ \mathrm{R}\left(1 + \frac{\text{sin. } \alpha \times \text{cos. } (\alpha + \frac{1}{2}\beta)}{\text{sin. } \frac{1}{2}\beta}\right) =$$

the joint effect of the ribs.

When the ribs occupy a semicircle, $\alpha = 45°$; and

$$2\ \mathrm{R}\left(1 + \frac{\cdot 7071 \times \text{cos. } (45 + \frac{1}{2}\beta)}{\text{sin. } \frac{1}{2}\beta}\right) =$$

the effect of the ribs; and if the semicircle be opposite the straining force, the ribs will resist compression, and those of the opposite semicircle should support an equal but tensile strain.

28.—If the ribs be so close as to form a continued surface, then R must express the resistance of the gore or portion of the ribs occupying the arc b; and in this manner the resistance of domes and other hollow solids may be estimated. It may also be applied to investigate the resistance of ships and other forms which are not circular, either by taking such a circular base as will approximate to the mean effect, or by actually summing the cosines of the angles by drawing them.

29.—In general the designs for framing may be so contrived that the load rests upon two or more points; for example, the weight of a roof acts on the truss which supports it only at the points where the purlins bear upon the truss; and when these points are supported by struts, the forces may be considered, without material error, to be in the direction of the principal rafters. But when the load is uniformly distributed over the rafter, and it is supported at the ends only, the strain upon the tie-beam is no longer in the direction of the rafter: and as there are some important strains produced by the action of uniform loads, the nature of these strains will form the next object of inquiry; and in order to render this inquiry more clear and simple, we shall suppose the load to arise from the weight of the beams themselves.

ON THE CENTRE OF GRAVITY.

30.—In a heavy beam there is a single point by which it may be supported; and if so supported, it may be placed in any position, and remain at rest. Whereas, were it supported by any other point, it would rest only in certain positions.

This point is called the *centre of gravity* of the beam.

A beam AB, suspended by a pin at C (*fig.* 16, *Plate* II.), passing exactly through the

centre of gravity, will rest in the position AB; or in that shown by the dotted lines *a b*, or any other. And the same thing will take place let the body be ever so irregular, provided the support passes exactly through the centre of gravity.

The centre of gravity of a uniform cylinder or prism is in its axis and at the middle of its length.

In a triangle the centre of gravity is in a line drawn from the vertex, or any angle, to the middle of the base, or opposite side, and at a distance of one-third of that line from the base. In a parallelogram it is at the intersection of the diagonals.

In cones or pyramids the centre of gravity is in the axis and one-fourth of the height from the base.

31.—The place of the centre of gravity in various planes, lines, and solids, has been determined by mechanical writers, and as the subject is considered in most works on mechanics, it is not necessary to enlarge upon it here; because when the rules become complicated, it is easier to ascertain it by mechanical means; and in irregular figures such contrivance must be resorted to.

The following simple cases may, however, be found useful for reference. Let a denote the length of the line joining the vertex and middle of the base of any figure, and D the distance of the centre of gravity from the vertex.

1. In a plane triangle, $D=\frac{2}{3}a$.
2. In a right cone or pyramid, $D=\frac{3}{4}a$.
3. In a circular arc (D being measured from centre of curvature) $D=\frac{\text{chord}}{\text{arc}}\times\text{radius}=Ka$.
4. In a circular sector, $D=\frac{2}{3}\frac{\text{chord}}{\text{arc}}\times\text{radius}=\frac{2}{3}K\ a$.

For convenience of calculation the value of K is given in the following Table* for different angles subtended by the arc:—

Angle.	Value of K.
10°	·999
20	·995
30	·989
40	·980
50	·969
60	·955
70	·939
80	·921
90	·900

5. In a circular segment, $D=\text{radius}-\frac{\text{chord}^3}{12\,\text{area}}$.
6. In a hemisphere, $D=\frac{5}{8}a$.
7. In a segment of a sphere, $D=\frac{8\,\text{radius}-3a}{12\,\text{radius}-4a}a$.

* Tarn's *Science of Building* (Crosby Lockwood & Co.

8. In a sector of a sphere, D=radius $-\frac{2 \text{ radius}+3 \text{ depth of segment}}{8}$.
9. In a plane parabola, of which the line a is the axis passing through the focus, and the area is enclosed by a line at right angles to a, D$=\frac{3}{5}a$.
10. The centre of gravity of half a parabolic area is found by erecting a perpendicular to the line a at the centre of gravity of the whole parabola as found above and measuring thereon D$=\frac{3}{8}$ base.
11. In a paraboloid, or solid formed by the revolution of a parabola about its axis, D$=\frac{2}{3}a$.

32.—To find the centre of gravity of a trapezium, or plane figure enclosed by four unequal sides, divide it into two triangles and find the centre of gravity of each. Join the two centres of gravity, and the centre of gravity required will be upon this line, and at a distance from that of either of the triangles in an inverse ratio to the area of that triangle. Thus if a is the centre of gravity of one triangle whose area is A, b that of the other whose area is B, G that of the trapezium, then

$$\text{A} \times \text{G}\,a = \text{B} \times \text{G}\,b, \text{ or G}\,b = \frac{\text{A}}{\text{A}+\text{B}} \times ab,$$

or we have to divide the line ab in the proportion of the two areas A and B.

The general formula for the centre of gravity of a body which can be divided into two parts whose masses are A and B, is

$$x = \frac{\text{A}\,a + \text{B}\,b}{\text{A}+\text{B}},$$

x, a and b being the distances respectively of the centres of gravity of the whole and of the two parts, measured from any convenient fixed point. So that if any two of the distances are given the other can be found.

33.—The most useful mechanical methods of finding the centre of gravity are the following:—

To find the centre of gravity of a body with plain sides, suspend it by the cord AEB (*fig.* 17, *Plate* II.) fixed to the body at A and B, and passing over a pin E. When the body is at rest, by means of a line and plummet, draw a plumb or vertical line upon it, as at $a\,b$. Then slide the cord upon the pin E, so as to change the position of the body as much as possible; and when it is at rest again, draw another vertical line upon it, and where this vertical line crosses the former one will be the centre of gravity of the body.

Another method. Balance the body upon the edge of a triangular prism (see *fig.* 18), and mark a line upon it close by the edge of the prism; then change the position of the body upon the prism, balance it again, and a line drawn by the edge of the prism will cross the former one, and the point of intersection will be in a line corresponding to the place of the centre of gravity of the body.

The intersecting lines should cross each other as nearly at right angles as possible, since the nearer they cross at right angles the more accurately the point will be found.

The same thing may be done by laying the body upon a bench, and moving it so as to

balance over the edge, or till it be just on the point of falling off. Then mark a line along by the edge of the bench, and do the same in another position, which will in like manner determine the centre of gravity.

34.—It is a principle in mechanics, that when a body is supported and at rest, the directions of the supporting forces must either meet at the centre of gravity, or in a vertical line passing through it, except the forces be parallel to one another.

And when a body is supported by one or more planes, and the body is at rest, the pressure on the planes is in a direction perpendicular to their surfaces; when the pressure upon a plane is in an oblique direction, the body will not remain at rest, unless it be in consequence of the friction of the surfaces, which is neglected in this inquiry.

By the help of these principles it will be easy to determine the direction of the pressures produced by a heavy beam or other body in some of the most useful cases.

ON THE PRESSURE OF INCLINED BEAMS.

35.—Let AB be a beam (*Plate* II., *fig.* 19), resting against the vertical wall BD, and C its centre of gravity; the lower end resting on an abutment cut in the beam AD. Through the centre of gravity C, draw the vertical line $c\ e$; and draw cB perpendicular to BD, meeting $c\ e$ in c. Join Ac, which will be the direction of the pressure against the abutment at A; and that the beam may have no tendency whatever to slide, the abutment should be perpendicular to Ac.

Also, if $c\ e$, taken from a scale of equal parts, represent the weight, and $a\ e$ be drawn parallel to cB, then $a\ e$ will represent the pressure against the wall at B, and $c\ a$ the pressure against the abutment at A. The horizontal thrust at the abutment A is also measured by the line $a\ e$; as it is always equal to the horizontal pressure against the wall at B. The pressures of shed or lean-to roofing are shown by this example.

36.—Where the rafters of a roof are uniformly loaded, there is obviously an angle which renders the oblique pressure $a\ c$, *fig.* 19, the least possible; for the weight of covering increases with the length of the rafter, and the oblique stress increases when the rafter is shortened. We shall show that the oblique stress $a\ c$ is the least possible when the *tangent* of the angle of inclination is ·7071, or the angle 35° 16′; for let w be the weight on a foot in length of the rafter, and l its length, S=AD, and x=BD; then $w\ l$=the load; and $a\ c$ is proportional to $\sqrt{x^2+\frac{1}{4}\,S^2}$;

$$\text{therefore, as } x : \sqrt{x^2+\tfrac{1}{4}\,S^2} :: w\,l : \frac{w\,l\,\sqrt{x^2+\tfrac{1}{4}\,S^2}}{x} =$$

the oblique stress at the abutment, which is a minimum when $x^2=\frac{1}{2}\,S^2$; or $BD^2=\frac{1}{2}\,AD^2$, whence $BD=AD\sqrt{\frac{1}{2}}$, and tan. $BAD=\sqrt{\frac{1}{2}}$,=·7071, or BAD=35° 16′. The horizontal thrust and stress on the rafter both increase with the weight, and have no minimum; and to the stiffness of the rafter we may extend the same remark. It is altogether a different question to determine the best angle for lock-gates. (See Art. 53.)

37.—Let AD be a smooth horizontal plane, and BD a smooth vertical plane (*Plate* II., *fig.* 20); the force which the end A, of the beam AB, would exert in a horizontal direction

in any position of the beam, may be found by the equation $\frac{W \times m \cos. \alpha}{h}$ = the horizontal thrust: where W is the weight of the beam, m the distance AC of the centre of gravity C from the lower end; α the angle which the beam forms with the horizon; and h the height BD of the upper end of the beam.

If instead of h, the height of the beam, we call l the length of it, then $\frac{W \times m \cos. \alpha}{l \sin. \alpha} = \frac{W m}{l} \cot. \alpha$, will be the horizontal thrust; or otherwise, let fall a perpendicular CE; then calling AE=b, we have the horizontal thrust $= \frac{W b}{h}$: that is, it is equal to the weight multiplied by the base AE and divided by the height BD. The thrust therefore varies directly as AE, and inversely as BD.

38.—It has been already stated, that the abutment should be perpendicular to AC (*fig.* 19) the direction of the pressure (Art. 35); so that the *tangent* of that angle which the abutment for the lower end should form with the horizontal plane is equal to the *co-tangent* of cAD, or to $\frac{ce}{ce'}$, which is equal to $\frac{m \times \cos. \alpha}{h}$, or $\frac{m \cos. \alpha}{l \sin. \alpha} = \frac{m}{l} \cot. \alpha$; which becomes $\frac{AD}{2h}$ when the centre of gravity is at the middle of the length of the beam. Hence the angle may be easily calculated.

39.—When the beam moves between the planes, so that the lower end slides along the plane AD, *fig.* 20, and the upper end down the plane BD, the centre of gravity C will describe a portion of an ellipse, of which BC will be the semi-transverse, and AC the semi-conjugate axis; except when the centre of gravity is in the middle of the length of the beam, when it will describe a circle, of which the radius is equal to half the length of the beam. This curious property may in many cases be applied to describe an ellipse on a large scale with advantage, as it is simple and easy to put in practice almost in any situation. The curved line in *fig.* 20 shows the part of an ellipse so described.

40.—When two similar and equal beams, AD and DB, are placed in the position represented in *fig.* 21, C,C′ being their centres of gravity, then their pressures against each other, at the point where they meet, will be equal and opposite; and their horizontal thrusts will also be equal, and may be found by Arts. 35 and 37: as each beam is obviously in the same state as that in *fig.* 19.

As the horizontal thrust of a roof is nothing more than a particular case, which is easily solved by the same rules, it will be sufficient to give the equation in Art. 37, in words at length, with an example of its application to that purpose.

RULE *for the Horizontal Thrust of an inclined Beam.* Multiply the weight in pounds by the *cosine* of the angle of inclination; and multiply this product by the distance, in feet, of the centre of gravity from the lower end; divide the last product by the height DE in feet, and the quotient will be the horizontal thrust in pounds.

Example. Let the weight distributed over the length of a rafter be 1,600 lbs.; the angle of inclination 27 degrees, of which the *cosine* is ·891; and the distance of the centre of gravity from the lower end, 7 feet; the rise or height DE being 6 feet 6 inches, or 6·5 feet.

Then, $\frac{1600 \times \cdot 891 \times 7}{6 \cdot 5} = \frac{9979 \cdot 2}{6 \cdot 5} = 1{,}535$ lbs., nearly, for the horizontal thrust, which is not much less than the weight in this particular case.

See also the rule, Art. 37.

When the centre of gravity is at the middle of the length of the rafter, the rule becomes more simple, and may be stated as follows:—

RULE, when the centre of gravity is at the middle of the length of the rafter or beam. Multiply the weight in pounds by the distance AE, in feet (which in a roof is half the span), and divide the product by twice the height, DE, in feet, and the quotient will be the horizontal thrust.

Example. The weight uniformly distributed over a rafter is 200 lbs.; the span of the roof is 20 feet, half of which is 10 feet; and the height of the roof is 5 feet. Then, $\frac{200 \times 10}{2 \times 5} = 200$ lbs., the horizontal thrust, which is exactly the same as the weight, and will always be so when the roof rises exactly one-fourth of the span, or at an angle of 26° 34′, but not in other cases.

41.—Let us now suppose a weight to be laid on at D, in *fig.* 21, its effect would be to press the beams in the directions of their lengths, as has been shown, and the magnitudes of these pressures may be found by the former Articles. (See Arts. 4 and 9.) Hence we see that a beam performing the part of a strut or an oblique support is often strained by two forces, the one being caused by the weight supported, the other by the weight of the beam itself, or some uniform load; and it is a well-ascertained fact, that a beam pressed in the direction of its length is very much weakened by a cross strain of this kind. If a beam happen to have a slight natural curvature, the convex side should be placed upwards, which will counteract the effect of the weight of the beam.

42.—It is easy to alter the directions of the pressures of a beam by altering the position of the supporting surfaces. If, for example, the beam AB, *fig.* 22, were cut so as to rest upon two level plates at A and B, the beam would have no tendency whatever to slide, notwithstanding its inclined position, and consequently it would have no horizontal thrust. The carpenter may in many cases take advantage of this circumstance in preventing oblique strains upon the points of support; for those supports may be abundantly strong to resist a perpendicular pressure, and yet be incapable of sustaining a very small force in an oblique direction; but this expedient fails when the intermediate framing bends.

The present example shows that by cutting the rafters of a shed-roof, so that they may rest level upon the plates, the roof will have no tendency to push out the lower wall.

43.—To find the perpendicular pressure upon the points of support, draw the horizontal line $a\ b$ through G the centre of gravity of the beam.

Then $\frac{W \times b\,G}{a\,b}$ is equal to the pressure on A,

And, $\frac{W \times a\,G}{a\,b}$ is equal to the pressure on B;

Or, as bG : aG : : pressure on A : pressure on B.

The relations between the weight W and the pressures on the points of support, are the same in a straight beam, laid in a horizontal position upon two supports, *fig.* 23.

ON THE STRAIN UPON BEAMS LAID HORIZONTALLY.

44.—When beams are employed in buildings in a horizontal position they are usually loaded in one or other of the following ways :—1. Beam fixed at one end and loaded at the other, or the load distributed over the whole length. 2. Beam supported or fixed at both ends and either loaded at one or more points, or with a weight equally distributed over its entire length. 3. Beam supported at the two ends and also at one or more intermediate points, being loaded between the supports.

45.—*Beam fixed at one end, loaded at the other, or with a distributed load.* When a beam whose length is AB is fixed at A in a horizontal position and strained by a load W at B, a leverage is produced upon the wall at the point A tending to lift it up or to break off the beam at that point; and this strain increases with the distance of W from A, and also with the increase of the weight W; therefore the strain at A is proportional to W × AB, which is called the *moment* of W about A. If we call M the moment of the strain caused by the loa,d and l the length of the lever or distance from the point strained at which the load acts, we have in this case

$$M = W . l.$$

If the load W is uniformly distributed over the whole length of the beam, and w is the load per unit of length, then $w . l = W$; and the several units of load will be so many equal and parallel forces, of which the resultant equals their sum and must act at the middle point between A and B; so that in this case the leverage is only one-half what it is in the former case, where the load is at the end B. Hence we have

$$M = \tfrac{1}{2} W \times l = \tfrac{1}{2} w . l^2.$$

And for the strain upon any other point C of the beam at a distance x from B, we have

$$M = \tfrac{1}{2} w . x^2.$$

From this it appears that when a beam is laid in a horizontal position, as in *fig.* 23, and a load is uniformly distributed over its length, or the beam is only loaded by its own weight, the strain upon the beam is the same as if half the weight were acting at its centre of gravity.

But if the weight be distributed over the beam it must be of a yielding nature, otherwise this rule will not hold good. If a strong short beam be laid upon the first beam, and the weight upon that, the strain upon the lower beam would be removed to the points where the ends of the short beam would rest upon the longer one, and of course the strength of the longer one would be much increased.

46.—*Beam supported at two ends and loaded at any intermediate point*, as AB (*fig.* 24, *Plate* II.). The load W will produce vertical reactions (which we will call P and Q) at A and B; then if we suppose C to be a fixed fulcrum, and weights equal to P and Q to be placed at A and B, the beam is strained in the same manner as at first supposed, and P × AC or Q × BC will be the moment of strain at C. Then taking moments about A, we have

$$Q \times AB = W \times AC, \text{ or } Q = W \frac{AC}{AB}.$$

Therefore we have for M the moment of strain at C—

$$M = Q \times BC = W \frac{AC \cdot BC}{AB};$$

or, if l is the span and a and b the lengths AC, BC, into which l is divided by the point C, we have

$$M = W \frac{a \cdot b}{l}.$$

If $a = b$, or the point C is at the middle of the beam, then

$$M = \tfrac{1}{4} W \cdot l.$$

And since the product $a \cdot b$ is greatest when a and b are equal, or are each equal to $\frac{1}{2} l$, it follows that when a beam is supported at the ends, as *fig.* 24, the stress arising from any weight W produces the greatest strain when it is applied in the middle of the length. And, if w be the greatest weight the beam would support in the middle, the greatest weight W that it could support at any other point C will be found by the following proportion:—

As the distance AC multiplied by the distance BC,
Is to the square of half the length of the beam;
So is the weight w, that could be supported in the middle,
To the weight W that could be supported at the point C.

From this it appears, that a beam 20 feet long will bear very nearly double the weight, at 3 feet distance from one end, that it would bear in the middle of its length; for $3 \times 17 = 51$ and $10^2 = 100$. Consequently the further a load can be removed from the middle of the beam the less is the strain upon it: and when it is necessary to place the stress at or near the middle, it is of great importance to cut the timber as little as possible with mortises at the point where the stress acts, and the piece should be as free as possible from knots in that point. Also, as a beam is generally weakest at the point strained, the same precautions should be attended to wherever the strain may be.

47.—If w be the greatest weight a beam whose length is L will bear in the middle of its length, and it be required to support by that beam any greater weight W, the point C may be found by this equation, $\frac{L}{2} \times (1 \pm \sqrt{\frac{W-w}{W}}) =$ the distance of the point C from either end. The upper sign gives the distance from the remote end, the lower sign gives the distance from the nearer end.

48.—When the load W is uniformly distributed along the beam AB, it can be shown, as in Art. 45, that the moment of strain is half what it is when W is all at the middle; so that in this case we find the moment of strain at the centre to be

$$M = \tfrac{1}{8} W \cdot l.$$

49.—*Beam supported at both ends and loaded at two or more points.* Suppose the weights P and Q to be applied at points distant respectively p and q from A, and W their resultant.

which is equal to P + Q, to act at C, whose distance x from A is to be found. Then by taking moments about A we have

$$W \cdot x = P \cdot p + Q \cdot q, \text{ or } x = \frac{P \cdot p + Q \cdot q}{P + Q}.$$

Therefore we have for the moment of strain at C—

$$M = W \frac{(l - x)\, x}{l}.$$

If there is a third weight S acting at a point whose distance from A is s, we shall have

$$x = \frac{P \cdot p + Q \cdot q + S \cdot s}{P + Q + S},$$

and so on for any number of weights with which the beam may be loaded.

50.—*Beam supported at three or more points in its length.* If the beam AB (*fig.* 24) is supported at A and B, and also by a prop or wall at C, the moment of strain produced by any load between the points A and C or B and C will be the sum of the moments of the two parts into which it is divided by the point C, as we may consider that it consists of two separate beams whose lengths are a and $l-a$ respectively. If these moments are M_1 and M_2, and there is a load w_1 in the middle of one portion, and of w_2 in that of the other, we shall have

$$M_1 = \tfrac{1}{4} w_1 \cdot a,\ M_2 = \tfrac{1}{4} w_2 \cdot (l - a),\ M = M_1 + M_2 = \tfrac{1}{4} \left\{ w_1 \cdot a + w_2 (l - a) \right\}$$

when $a = \frac{1}{2} l$, and $w_1 = w_2 = \frac{1}{2} W$, we get $M = \frac{1}{16} W \cdot l$;

or, the moment of strain when there is a prop at the centre is one-fourth what it is when there is no intermediate support, or the beam may be loaded with four times the weight to produce the same amount of strain. If there are two props dividing the beam into three equal parts, the strain will be one-ninth of what it is when there are no props, or the beam may be loaded with nine times the weight to produce the same strain. Generally, if a beam is supported by props dividing its lengths into n equal parts, and all the parts are loaded equally, the weight which may be put upon it when supported only at the two ends is to be multiplied by n^2 in order to produce the same amount of strain in the propped beam. (See also Art. 94.)

ON STRESS FROM THE PRESSURE OF FLUIDS.

51.—The pressure of a fluid exerts its force in a direction perpendicular to the surface it acts upon, and is equal to the weight of a column of the fluid, the base of which is equal to the surface which the fluid acts upon, and the height equal to the depth of the centre of gravity of that surface below the surface of the fluid. The same rule applies to semi-fluid materials; but in loose earthy matter the pressure is less, though not sufficiently so to allow of reducing the strength of a timber support, because in such situations it is so much more likely to decay. Since the weight of a cubic foot of water is 62·5 lbs., the area of the part

exposed to the stress in feet, multiplied by 62·5 times its mean depth in feet, will be the stress in pounds.

If the length of a plank be horizontal, and it be sustained at the ends, the stress will be equal on every part of the length, and its stress will be found by the rule (Art. 108).

When the plank is placed with the length vertical, and is sustained at the ends, the pressure increases as the depth, and the point of greatest stress may be considered to coincide with the *centre of pressure* which is the point at which the resultant of all the pressures on the surface acts, and is at the distance of two-thirds of the depth from the surface of the fluid, when the upper fixed end of the plank coincides with that surface. The stress will be found by the preceding rule, using 31·25 instead of 62·5 as the multiplier.

Where the plank or beam is horizontal, it may be arch-formed in cases where there are abutments; and since the pressure is equal and perpendicular to the curve in every part, the curve of equilibrium must be a portion of a circle; in this case the strength is easily calculated, for the strain is inversely as the radius of curvature. (Art. 130.)

ON THE STRESS ON THE GATES OF CANAL LOCKS, &C.

52.—This is a subject of some importance, and has not been treated with clearness nor simplicity. In fact it has evidently not been understood in theory; and consequently, the construction now followed has been the result of the frequent practical application of various modes of construction, by which the good ones have gradually become known. It is, however, an imperfect mode of acquiring knowledge, which may be followed in cases where the nature of the causes are not understood, but to these it should be confined.

Lock-gates may be either straight or curved; in either case the pressures of the fluid being perpendicular to the surface, their resultant will be *c e* (*figs.* 9 and 10); hence, if we

FIG. 9.

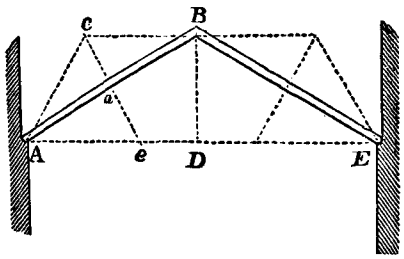
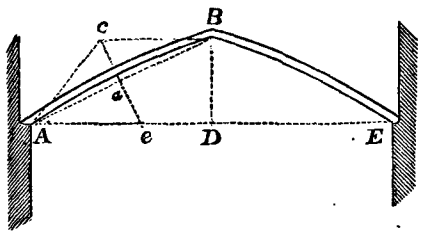


FIG. 10.



measure *c e* by such a scale of equal parts as will represent the pressure in pounds, then *c*A measured by the same scale gives the pressure at A, and its direction is *c*A: also, A*e* measured by the scale gives the pressure at the angle B where the gates meet, its direction being *c*B; it represents the force which closes the joint of the gates, and must have an equal and opposite force from the action on the opposite gate. To draw the directions of the forces let *a* be the middle of the breadth of the gate AB, and through this point *a* draw *c e*

perpendicular to AB; also, draw cB parallel to the line joining the centres of motion A, E, which determines the point c, and join cA. The stress on the gate will be found by Art. 51, and when the gates are curved, the curve should be a circle drawn to touch Ac and cB as tangents; in that case the gate resists as an arch; but as the curve is flatter the stress is more transverse, and becomes wholly transverse when the gate is straight.

53.—The best angle for lock-gates has often been discussed, but never decided. Belidor's attempt is a very imperfect one; it gives the angle 135°. Muller's is better; it gives the angle 109° 28′, but is evidently inaccurate in assuming the equality of two strains which are not equal. Robison gives Muller's method, with his doubts of its accuracy, but makes no effort to free the subject from its difficulties. Telford follows the example of Robison; adding that one-sixth of the width is the proportion esteemed customary by practical writers, but that the gates of the sea-lock of Muyden form an angle of 145°, and that the ancient lock of Sparendam has a sally of about one-sixteenth at the sea doors. Professor Leslie's researches lead him in the opposite direction; for he concludes that 90° is the best angle. These opposite results have enough in themselves to raise some interest in the research; but we cannot do more than refer to them, and then proceed to consider the question anew.

54.—The gates of a lock must have a proper degree of strength; and it is obvious that the most important thing in practice is to give the gates such an angle that, with the proper degree of strength, they shall be of the least weight possible; and it is further clear that gates of the least weight, but yet sufficiently strong, cannot be a means of exciting great or injurious strains on the other parts of the lock. This condition, therefore, seems to be the most essential to a lock-gate, both as to strength and convenience in practice. But the thickness necessary for the strength is directly as the radius of curvature, when they are curved to the form of equilibrium (Art. 51); and if y be half the breadth AD of the lock, and x the sally BD of the gates, then this radius is, according to the relations of the lines in a circle, $\frac{y^2 \times x^2}{2x}$; hence, this expression is proportional to the thickness necessary for strength: and assuming the arc to be a constant multiple of its chord, its length will be as $\sqrt{(y^2 + x^2)}$; and the weight varying as the length and thickness, it varies nearly as $\frac{(y^2 + x^2)\sqrt{(y^2 + x^2)}}{2x}$; therefore, this expression should be a minimum.

According to the rules of maxima and minima, we find this to be the case when $2x^2 = y^2$, or $1{\cdot}4142\, x = y$; and the angle formed by the chord lines of the gates would be 109° 28′, the same result as Muller found for straight gates; and the salient angle BAD will be 35° 16′.

55.—If the gates be straight, or the curvature be flatter than the curve described to pass through the angle from abutment to abutment, then the strength of the gates must be greater in the same proportion as is required for the resistance of lateral pressure: and as shortening the gates reduces the effect of the lateral pressure, the angle may be increased with advantage in such gates; for the weight varies as the power of resisting lateral pressure, which is as $\sqrt{(y^2 + x^2)}$, or as the length; that is, other things being the same, the thickness must be directly as the length; and hence $\frac{(y^2 + x^2)^2}{x}$ is proportional to the weight, and should be a minimum, which it is when $3x^2 = y^2$, or $1{\cdot}732\, x = y$; and the angle corresponding is 120°, in which case the salient angle BAD will be 30°.

Our general result, therefore, is, that for straight gates the angle should be 120°, or the sally about two-sevenths of the width of the lock; and for gates in one continued curve from abutment to abutment, the versed sine of the curve should be about seven-twentieths of the width. Practice is exceedingly variable, and it is well known that considerable variation on either side of the best proportion is not attended with any serious disadvantage.

56.—In an article on this subject in the first volume of the *Transactions of the Institution of Civil Engineers*, Mr. P. W. Barlow demonstrates that for straight gates the *salient angle* BAD should be 19° 25′ in order to give them the maximum of strength with a given section of timber, which makes the angle ABE 140° 10′. The following table gives the minimum scantlings of oak timbers, die square, for lock-gates of different lengths and depths which Mr. Barlow calculates to be requisite in straight gates.

Length of gate.	6 feet deep.	8 feet deep.	10 feet deep.	12 feet deep.	14 feet deep.	16 feet deep.	18 feet deep.	20 feet deep.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
5	4·86	5·35	5·77	6·13	6·45	6·74	7·01	7·26
6	5·49	6·05	6·52	6·92	7·29	7·62	7·93	8·21
7	6·09	6·70	7·22	7·67	8·07	8·45	8·78	9·10
8	6·66	7·32	7·89	8·39	8·83	9·23	9·60	9·96
9	7·20	7·92	8·54	9·07	9·55	9·98	10·38	10·75
10	7·72	8·50	9·16	9·73	10·24	10·71	11·14	11·54
11	8·23	9·06	9·76	10·37	10·92	11·41	11·87	12·30
12	8·72	9·60	10·34	10·98	11·57	12·10	12·58	13·03
13	9·20	10·12	10·90	11·59	12·20	12·76	13·27	13·74
14	9·67	10·64	11·46	12·18	12·82	13·40	13·94	14·44
15	10·12	11·14	12·00	12·75	13·42	14·03	14·55	15·12
16	10·56	11·63	12·53	13·31	14·01	14·65	15·24	15·78
17	11·00	12·11	13·05	13·86	14·60	15·26	15·86	16·43
18	11·43	12·58	13·55	14·40	15·16	15·85	16·48	17·07
19	11·85	13·04	14·04	14·93	15·72	16·43	17·09	17·70
20	12·26	13·49	14·54	15·45	16·26	17·00	17·68	18·31

Curved gates are usually employed as in the locks at St. Katharine's, London, and West India Docks, and considerable advantage is gained thereby. At St. Katharine's the width is 45 feet, the sally BD is 11 feet, and the radius of curvature 117 feet, the salient angle BAD being 26°.

At the West India Dock the width is the same, BD is 10 feet, and the radius 120 feet, the angle BAD being 24°.

In the London Docks the width is 40 feet and sally 9 feet, the radius being only 50 feet, and the angle BAD 24° 14′. In this last the curve approaches nearer to that of a complete arch than in the two former, and the transverse strain is reduced to less than half that of straight gates having the same salient angle, while in the two former it is nearly three-fourths.

ON THE EQUILIBRIUM OF AN ASSEMBLAGE OF BEAMS.

57.—When an opening is too wide to be spanned by one or even two pieces of timber, it may be effected by a combination of pieces which bear a near resemblance to an arch in masonry. The principles of stability are not, however, exactly the same: in a piece of carpentry the stability is gained by the transverse strength of the material, and the mode of connection; in a stone arch the stability is gained by its *compressive* strength, or resistance to crushing only, a proper disposition, and depth of the joints. The principles of equilibrium, as established by mathematical writers, require some modifications. When a combination of beams is strained by a force which tends to destroy the balance of its parts, if the strain at any part be examined, it will be found to be of two kinds, the one stretching, the other compressing; and in the depth of the framing there will be one point in a neutral state, in the same manner as in a solid beam. Now the curve of equilibrium should pass through the neutral points, and not form the inner line of the system of framing, as some writers assert. If the combination consisted of single frames, or blocks, without connection, but merely abutting against each other, the strain excited by the forces on any part would be wholly of the compressive kind, as it is in a stone arch, where we cannot trust to the cohesion of cements: but in a combination of beams, to lose the advantage of connection, is to lose that in which the excellence of the carpenter's art chiefly consists; therefore the latter case need not be considered.

ON THE POINTS OF FRACTURE IN A SYSTEM OF FRAMING.

58.—The balance of the parts in a system of framing is not so complicated a question as it is generally imagined to be; at least it is not so while our inquiries are confined to practical cases. A system of framing for spanning a wide opening is generally composed of two equal and symmetrical parts; and when it is loaded, the load is also similarly disposed. When the parts are loaded so as not to be in equilibrium, the system will divide itself into four parts only.

Again, if the system be balanced, and rupture be produced by a weight laid on at any particular point, the system may either divide itself into three or four parts. When the weight is laid upon the system at or near the middle of the span, it will divide itself into four parts. When the weight is laid upon it at some distance from the middle, the framing will generally divide itself into three parts.

59.—Let *fig.* 25, *Plate* III., represent a system of framing, which is similar to one employed by Sir Robert Seppings, Surveyor of the Navy, in the year 1817, for the roof of a dock for building ships under cover at Plymouth. The span from A to A′ was 95 feet 4 inches, and the extreme width 125 feet 4 inches. The parts of this roof are obviously not in equilibrium, and the weight of the roof itself tends to cause fracture at the points B, C, and B′, consequently to break the roof into four parts, AB, BC, CB′, and B′A′.

The uprights AB and A′B′ have neither position nor weight to balance the spread of the superior parts; and the stability of the system depends wholly on the strength of the post to

resist a cross strain, and the connection of the parts. By a proper disposal of the parts of this roof, the greater part of the strain arising from the weight of the roof itself might have been removed: and of course the roof would be either much stronger to resist any other force —such as the wind, &c.—or it might have been constructed with less material and labour.

This example is cited to show that it is as essential that the principles of equilibrium should be known, as it is to understand the best method of stiffening and connecting the parts. The roof of Sir R. Seppings is a fine example of the latter; and it has undoubtedly been for the purpose of leaving as much free space as possible that the upright posts only were used; for an oblique strut in the direction aB would have added much to the stability of the frame.

To find the position of the side posts, so that the roof may be in equilibrium. Let G be the centre of gravity of that part of the frame between B and C, *fig.* 26. Draw the vertical line $b\,g$ through G, and from the middle of the depth of the framing at C draw the horizontal line Cb, cutting the vertical line in b. Then draw the line ABb, and AB is the position of the post.

Here no notice is taken of the weight of the post itself, because it is too small to produce a sensible difference in the position.

60.—In *fig.* 25, B, C, and B′ may be called the points of fracture, or the centres of motion, which in this case are easily found by inspecting the figure. In general it is more difficult to ascertain their position, and they are affected by so many circumstances that it is not practicable to give a general rule for finding them.

But in most cases the positions of the centres of motion may be determined, with all the accuracy required in practice, by inspection; and it may be as well to illustrate this point before proceeding to examine these combinations further.

In the first place, suppose ACB, *fig.* 27, to be a solid curved beam, resting on the abutments A and B. Let it be uniformly loaded, and the strength equal in every part of its length; then the neutral line would be at or near the middle of the depth. Now if the curvature of the neutral line should not be the proper curve of equilibrium to the load, there would be a tendency to break at three points, one of which would be at C, the middle of the length. The other points would be near where the neutral line is most distant from the chord line AC and CB, but a little below, that is, at e and f in the figure.

61.—If the beam should be much weaker at any point b than it is at e, the centre of motion would be the point b, and one of the fractures would be there in the case of failure. But if the weak point were at d, the beam would be less liable to fail there, unless it should be very much weaker than at e.

Again, considering the strength to be equal throughout, and the load to increase from A and B towards C, then the fractures would take place at or rather above the points e and f. On the contrary, if the load should increase from C towards A and B, the fractures would be below the points e and f.

Hence, by attending to the form, the strength of the parts, and the disposition of the load, in a system of framing, the centres of motion or places of fracture may be determined with all the accuracy that is necessary in practice.

62.—But the constant load on a system of framing may be so balanced by the form of the supporting frame that it will have no tendency to produce fracture; and then the strength

should be capable of sustaining any other load of a variable nature, as the weight of carriages, &c., upon a bridge, or the like. In order that the load may be thus balanced, the form of the supporting frame should be such that a continued line, which will depend on the nature and disposition of the load, may pass through the middle of the depth of every part of the supporting frame. This line is called the *line of equilibrium.* Its nature may be more accurately defined, by stating that each element of the line is the resultant of all the forces acting on that element: it is, generally, a curved line; but in a vertical pillar or column it is a straight line drawn in a vertical direction through the centre of gravity.

The form of the curve may either be found by mathematical investigation, or by mechanical means, when the nature of the load is known.

63.—When in a system of bodies in the same plane, the parts are in equilibrium, the centre of gravity of the system is either the highest or the lowest possible; but when it is in the highest point the equilibrium is always *tottering*, and must be preserved either by the connection of the parts, or by the magnitude of the surfaces of contact: on the contrary, if the centre of gravity of the system be in the lowest point possible, the equilibrium is *stable;* and if the system be disturbed, it re-arranges itself again in the same form as before. In like manner, if in a system of bodies in the same plane, the curve of equilibrium be concave on the under side, the equilibrium is tottering; but when the curve is convex on the under side, the arrangement is in stable equilibrium. The bodies are here supposed to touch each other only at single points; in which case, of course, the curve convex downwards can only be obtained by giving the bodies a continued connection, as in a chain or suspension bridge; while the bodies arranged so as to have their curve of equilibration concave downwards (as in an arch) need no connection. In the former arrangement, as long as the load varies, the surfaces of contact must perpetually rub, and so become weaker and weaker till some link of the connection *wears out.* But in the arch-like arrangement, once rendered stable by giving those surfaces sufficient extent, there can be no friction, and therefore no wearing weaker. This difference should lead to some important ethical considerations in permanent bridge building.

TO DETERMINE THE CURVE OF EQUILIBRIUM.

64.—Let AC represent a portion of a curve of equilibrium, *fig.* 28, C being the vertex of the curve, and GE a vertical line passing through the centre of gravity of the load resting on the part between A and C.

Then by similar triangles, AE : GE (=CB) : : AB : BD : : horizontal thrust to the weight. Therefore, $\frac{CB \times AB}{AE} = BD$. But BD is the *subtangent* of the curve; consequently when it agrees with that of any known curve, that curve is the curve of equilibrium.

65.—*Example* 1. Suppose the load to be uniformly distributed over the framing, then the centre of gravity of the load over any portion AC may be considered to fall over the middle of AB, and AE will be equal $\frac{1}{2}$ AB. Consequently, BD = 2BC, a well-known property of the parabola. Therefore when the weight is uniformly distributed, the curve of equilibrium is a parabola. A method of describing a parabola will be found in the section on Roofs (Sect. IV.).

Various other methods are given in Tarn's *Practical Geometry*;* and an easy method is also given by Nicholson, in his *Carpenter's Guide*.*

As in bridges and roofs the weight is very nearly uniformly distributed, it will generally, be near enough for practice to use the parabola as the curve of equilibrium; where greater accuracy is required, it may be found by Art. 67.

66.—*Example* 2. Let the weight on any part of the framing be proportional to the distance from C, the middle of the span.

Then the distance AE will be equal to $\frac{1}{3}$ AB; because the distribution of the weight may be represented by a triangle, with the vertex at C and base at A. In this case BD = 3 BC, a property of the cubic parabola. Hence, when the weight is distributed in proportion to the distance from the centre, the curve must be a cubic parabola. To describe this curve, put s = half the span, and h = the rise of the framing; x the abscissa, and y the corresponding ordinate. Then by the property of the curve, $a\,x = y^3$; and, when $x = h$, and $y = s$, $a\,h = s^3$, or $a = \frac{s^3}{h}$; therefore $\frac{s^3 x}{h} = y^3$, or $s\left(\frac{x}{h}\right) = y = s\,n\,\frac{1}{3}$, when $x = n\,h$.

The curve may also be constructed by the following method:—

Divide the rise BC (*fig.* 29) into eight equal parts, and draw the horizontal lines $a1, b2, c3$ &c. Then the distance

AB	multiplied by	0·5	will be equal	a 1,
AB	,,	0·63	,,	b 2,
AB	,,	0·721	,,	c 3,
AB	,,	0·7937	,,	d 4,
AB	,,	0·855	,,	e 5,
AB	,,	0·9085	,,	f 6,
AB	,,	0·956	,,	g 7.

Through the points a, b, c, d, e, f, g, draw the curve, and it will be the cubic parabola sufficiently near for practice.

Whenever the distance of the centre of gravity from A (*fig.* 28) is expressed by the equation AE = $\frac{1}{m}$ AB the curve of equilibrium will be a parabola, of which the equation will be $a\,x = y^m$, and the *subtangent* = $m\,x$.

It is useful to know the *subtangent* of the curve of equilibrium, because it gives the *tangent*, and consequently the direction of the pressure of the abutment. In any case, where the equation of the curve of equilibrium is $a\,x = y^m$, the pressure on the abutment will be in the direction of a line, which makes an angle with the horizon, of which the *tangent* is $\frac{m\,h}{s}$, where s = half the span, and h = the rise. And also, when we make w = the weight of half the framing, we have $\frac{s}{m\,h}\,w$ = the horizontal thrust.

67.—*Example* 3. When the weight is distributed over a piece of framing, a bridge for example, so that the weight on any portion from the middle towards the abutment shall be represented by a trapezium AFHC, *fig.* 30, put HC = a, which will represent the weight at the middle of the arch; and let IC : IA : : 1 : n; then $a\,y + \frac{1}{2}\,n\,y^2$ = the weight on any portion of the arch whose horizontal ordinate is y. Put AB = y (*fig.* 28) and CB = x, and we have

* Crosby Lockwood & Co.

$\frac{3x(ny+2a)}{ny+3a}$ = BD, the *subtangent* of the curve. Consequently, when the point A is at the abutment, and $y = s$ = half the span, and $x = h$, we have $\frac{3h(ns+2a)}{s(ns+3a)}$ = *tangent* of the angle which the direction of the pressure on the abutment makes with the horizon. And $\frac{s^2}{6h}(3a + ns)$ = the horizontal thrust at the abutment.

But in order to construct the curve, its equation should be known; to effect this put H = the horizontal thrust, and by converting the relations of the forces into an analogy, we have $H : ay + \frac{1}{2}ny^2$ (the weight) $:: y :$ to the *subtangent* BD, by Art. 56; hence, this value of the *subtangent* is $= \frac{ay^2+\frac{1}{2}ny^3}{H}$. But by the principles of the differential calculus, $\frac{y\,dx}{dy}$ = the subtangent, therefore $\frac{ay^2+\frac{1}{2}ny^3}{H} = \frac{y\,dx}{dy}$, or, $H\,dx = ay\,dy + \frac{1}{2}ny^2\,dy$; and by integration we have, $Hx = \frac{1}{2}ay^2 + \frac{1}{6}ny^3$; whence $x = \frac{y^2}{2H}(a + \frac{1}{3}ny)$ is the equation of the curve.

This equation will be sufficiently accurate for determining the form of the curve in most cases; as the expression for the weight will nearly agree with the distribution most commonly occurring in practice. The abscissa x, and ordinate y, become h, and s, at the abutment; and these being always given, we have $H = \frac{s^2}{2h}(a + \frac{1}{3}ns)$; and H, being determined either by this method, or as above, the equations being actually the same, the ordinates of the curve may be easily calculated.

The curves that apply to such cases as usually occur in practice are evidently of a parabolic kind; and the same observation applies to those curves which are proper for cupolas or domes, to which we must now proceed.

TO DETERMINE THE CURVE OF EQUILIBRIUM FOR A CUPOLA OR DOME.

68.—Conceive the dome to be generated by the motion of the curve AC (*fig.* 28) round CB as an axis; then the same relations will obtain as in the case of an arch (Art. 64), that is, $\frac{CB \times AB}{AE}$ = BD = the *subtangent* of the curve of equilibrium. Let A′I (*fig.* 31) be the plan of the dome, and let it be divided at the circumference into any number of equal parts, of which HF is one; then, whatever form is necessary to equilibrate the gore HFC′, must be equally requisite for every other part of the dome. Let ACB be a section through A′C′ the middle of the gore HFC′.

69.—*Example* 1. When the weight is uniformly distributed.

In this case the weight on any part of the gore is proportional to the distance from the centre; consequently, the centre of gravity is $\frac{1}{3}$ AB from A: and the curve of equilibrium is a cubic parabola, the same as in Example 2, Art. 66; and may be described in the same manner.

70.—*Example* 2. Let the weight be distributed so that on any portion of it, AC, *fig.* 31, the load is $= ya + \frac{\pi b y^3}{3}$, where y is the ordinate AB, a the depth of an uniform weight; and $1 : b$ the ratio of increase of another part of the load, which increases regularly

from the centre to the circumference; also $\pi = 3{\cdot}1416$, the circumference of a circle whose diameter is 1.

By the same process as in Art. 65 we obtain $x = \frac{y^2}{2\,\mathrm{H}}(a + \frac{1}{3}\,\pi\,b\,y^2)$; where x = BC the abscissa; and H = the horizontal thrust.

Hence, when the rise and radius of the base of the dome are given, the rise or height being h, and r the radius, we have $\frac{r^2}{2\,h}(a + \frac{1}{3}\,\pi\,b\,r^2) = \mathrm{H}$.

The most useful cases of domes will be determined by this equation, from which it is easy to find a sufficient number of points in the curve to design the framing upon. It is scarcely necessary to remind the reader that in domes, as in arches, the curve of equilibrium ought to pass through the middle of the framing.

71.—*Example* 3. Suppose the curved part of the dome, *fig.* 32, to be uniformly loaded, and a lantern on the top, the space CD being open.

Let W be the weight of the lantern, and $w\ \pi\ y\ (y + r)$ = the weight pressing on the curved surface AC, where y = AB, r = CE the radius of the lantern.

The whole weight is $w\ \pi\ y\ (y + r) + \mathrm{W}$, and the equation of the curve of equilibrium is $\frac{y}{\mathrm{H}}(\frac{1}{3}\,w\,\pi\,y^2 + \frac{1}{2}\,w\,\pi\,r\,y + \mathrm{W}) = x$.

Let the radius of the base of the dome be R + r, and h the height of the base of the lantern. Then, $\frac{\mathrm{R}}{h}[w\,\pi\,(\frac{1}{3}\,\mathrm{R}^2 + \frac{1}{2}\,\mathrm{R}\,r) + \mathrm{W}] = \mathrm{H}$ = the horizontal thrust.

72.—From the equatations in the two preceding articles the proper curve for a dome may be obtained; but it may be remarked, that so long as the curve is not more convex towards the external surface than the proper curve of equilibrium, the form may be changed at pleasure; because every part of the framing may be strutted so that it cannot press inwards; but the lateral stability decreases in proportion as we get within the proper curve. On the contrary, a departure from the curve of equilibrium outwards may be compensated by ties, and such must always be the case at the springing of a dome. In a dome of masonry, as the materials of each horizontal circle prevent each other from pressing inward (as a circle of struts in a timber dome), the profile may deviate inward as much as we like from the curve of equilibrium (which is the *weakest* form that will stand at all), even to straightness, which reduces the dome to a *cone* like that employed by Sir Christopher Wren to support the lantern of St. Paul's, which, if sufficiently hooped at the base, is safer than any dome.

The curve of equilibrium is not the weakest form for a timber dome, as Dr. Robison states it to be, but it is the limit that should never be exceeded in outward convexity. The curvature of the line of equilibrium passing through the framing may be of any form within this, and be stronger; but if it be without this, it will be weaker, and require hoop-tying about the middle parts of its height.

From the mutual tendency of the parts to the axis, a dome admits of an opening in the centre; but it is not a matter of indifference whether the weight be omitted or not in determining the curve of equilibrium. The reader will, however, easily perceive that the external covering may have any form that is most consistent with the other parts of the building, as these calculations refer to the supporting frame only. The strongest forms are generally the most beautiful, but the consideration of beauty of form does not come within the plan of this work.

GENERAL OBSERVATIONS ON DESIGNING FRAMING.

73.—The principal questions relative to the action of forces on single beams, and on systems of framing, have now been considered; and it only remains to make a few remarks on the best method of applying those principles so as to form a perfect design.

In the first place, the artist must bear in mind the axiom, *that the strength of a piece of framing, whatever may be the design, can never exceed that of its weakest parts; and that partial strength produces general weakness.*

Therefore, let the fixed conditions, or those objects which cannot be altered, be well considered; and, as far as it can be done, let them be drawn correctly to a scale, showing the curves of equilibrium, the points where the forces act, and every other particular condition. Also, it must be considered whether the forces are to act constantly on the same parts, or to be subject to changes; and the nature and extent of these changes should be exhibited.

Secondly. The nature of the sustaining points should be carefully examined, whether they be capable of resisting a force acting obliquely against them or not; and the framing must be disposed accordingly.

Then a design may be sketched in, of such a nature as shall appear best adapted to attain the objects in view, taking care to avoid transverse strains as much as possible, to load obtuse angles lightly, and to give little excess of strength to parts which themselves add to the load to be supported; the proper degree of strength may be fixed by the rules in the next section.

Nothing will assist the artist more in forming a good design than just conceptions of the objects to be attained; and nothing will render those objects more familiar to the mind than drawing them.

SECTION II.

ON THE RESISTANCE OF TIMBER, OR THE STABILITY OF RESISTANCE.

74.—To know the resistance which a piece of timber offers to any force tending to change its form, is one of the most important species of knowledge that a carpenter has to acquire; and to be able to judge of this degree of resistance from observation only, even in common cases, requires nothing less than the practice of a life devoted wholly to carpentry.

Besides, it is a species of knowledge that is confined to the person who has obtained it, and dies with him. It is a feeling of fitness, which can neither be communicated nor described; nevertheless, it is a feeling that every thinking practical man is sensible he possesses. We are far from having a wish to banish the nice observation which gives birth to this feeling, because it is more desirable that it should be encouraged than suppressed; but there are cases where it fails: that is, when the magnitude of the object is beyond the range of ordinary practice, and where new combinations are attempted. In such cases the laws of the resistance of solids should be referred to, even by the most expert practical man; and he will be better able to judge of their correctness if he finds them, in common cases, to give results that agree with those he has drawn from practice.

But there are many besides practical carpenters who ought to know something of the principles of building, and who have not an opportunity of becoming acquainted with those principles through practice: to such persons the rules and experiments detailed in this work will be found extremely useful.

In order to be able to determine the dimensions or scantling of a piece of timber, which shall be capable of sustaining a given weight or pressure, the laws that regulate its resistance should be considered; and to accomplish this in a manner likely to be useful, we must consider what effect is produced when a piece of timber is overloaded. This effect, in general, is nothing more than a certain degree of flexure, or bending, as it seldom happens that timbers are absolutely broken; and, generally, a small degree of bending renders a beam unfit for its intended purpose.

Much has been said on the irregular nature of timber, and that it is impossible to make rules or tables for scantlings on that account; but it must be observed, that these remarks apply only to rules for the strength of timber to resist breaking; and even in that case timber is not so irregular as is generally imagined. The difference in good timber is still less perceptible when the bending only is considered, and the laws of flexure are founded on experiments of the most unexceptional nature. It has been shown in the preceding section

(Section I., Art. 18) that a change in the position of the resisting parts brings new forces into action, and this is the cause of the irregularity observed by Buffon in his experiments; but in a piece of carpentry these changes must never be so great as to produce a sensible effect: therefore it would be a needless refinement to attempt to form rules that would embrace all the circumstances these changes produce; besides, it would render them too complicated to be useful.

In all cases timbers that are exposed to considerable strains ought to be of a good quality: therefore the data should be drawn from experiments on good timber, and not from inferior specimens. For if inferior specimens were made the basis of calculation, at what point of inferiority should we begin? And how should it be described so as to enable us to compare it with any other timber? But when it is known what a piece of good timber will do, it will be easy to compare its description with that to be used. Good timber is that which is perfectly sound, straight-grained, free from large knots or other defects, particularly near the strained points, and seasoned. Specimens of this kind are marked *medium* in the tables of experiments. In Section X. the reader will find further information respecting the nature and qualities of different kinds of timber.

But the qualities even of good timber vary in some degree according to the nature of the earth it is grown upon, and the dryness and exposure of the situation. The age of trees at the time of cutting, the natural defects, such as knots, shakes, &c., also the mode of seasoning, or the comparative dryness, is the cause of some difference in the strength and stiffness of timber: all these things considered, it is impossible to calculate correctly its strength and stiffness. But, fortunately, that precision which is so essential to the philosopher is not absolutely necessary to the architect and engineer. They content themselves with approximations which are simple, and more easily obtained; and, provided the limits which cannot be passed with safety be pointed out, these approximations are sufficient to direct their practice.

DEFINITIONS, AND GENERAL PRINCIPLES.

75.—The laws of the resistance of materials depend on the manner in which the pieces are strained, and may be divided into three kinds.

First, When the straining-force tends to pull the piece asunder in the direction of its length, the force developed in the material is the *resistance to extension*, or the *tensile strength*.

Secondly, When the straining-force tends to break the piece across, the force which is developed is the *resistance to cross strains*.

Thirdly, When the straining-force tends to compress the body in the direction of its length, the force developed in the body is the *resistance to compression*.

76.—*Stiffness* is that property of bodies by which they resist flexure or bending. *Strength* is that by which they resist fracture or breaking. This distinction must be carefully attended to, because the laws of strength and stiffness are not the same. For instance, the stiffness of a cylinder, exposed to a cross strain, increases as the fourth power of the diameter, but the strength increases only as the cube of the diameter. If the diameter of a cylinder be doubled, its stiffness will be sixteen times as great, but its strength will only be increased eight times.

In those members of carpentry that are unavoidably subject to cross strain, the

comparative stiffness is of much greater importance than the comparative strength, as timbers are seldom exposed to strains that would break them.

77.—All bodies may be extended or compressed; and within the limits useful in practice, the extension or compression is directly as the force producing it: that is, if a force of 100 lbs. produce an extension of one-tenth of an inch, 200 lbs. will produce an extension of two-tenths of an inch, and so on. It is on the truth of this principle that the greater part of the following inquiry depends; and it has been found by experiment to be perfectly regular to an extent which embraces all useful cases. It has no other proof than a large experience without a single exception; but this will be deemed a sufficient one.

ON THE RESISTANCE TO EXTENSION.

In conformity to the principal of distinguishing *stiffness* from *strength*, this subject divides itself into two parts.

On the STIFFNESS *of Beams to resist a Strain in the direction of their Length.*

78.—It is apparently the most simple case of extension when a piece is pulled in the direction of its length; but this simplicity is confined to the case where the line of strain corresponds exactly with the centre of the section, otherwise it is the most complicated, or at least the most difficult to manage in a theoretical point of view. When a beam is strained in the direction of its length, the extension will be obviously directly proportional to the straining weight, and to the length of the piece; and inversely proportional to its area, or to the product of its breadth and depth when the piece is rectangular. Hence, if L denote the length of a prismatic piece of timber having one square inch of section, which is strained by a tensile force W acting in the direction of its length and producing an extension e, then the quantity e is to the original length L as W to a constant E, determined by experiment for each kind of material, and called the *modulus of elasticity;* so that we have

$$\frac{e}{L} = \frac{W}{E}, \text{ or } e = \frac{W \cdot L}{E}.$$

And as the extension is inversely as the area of section, we have for a beam whose area of section is A—

$$e = \frac{W \cdot L}{E \cdot A}.$$

The Tables I., II., X., and XVI., at the end of the section, give the values of E obtained by different experimenters on various kinds of timber, W being in lbs., and all the dimensions in inches.

RULE I. To find the extension of a piece of wood under a stretching force; multiply the weight in pounds to be suspended by the length of the suspending piece in inches; this product divided by the value of E in Tables I., II., X., and XVI., corresponding to the kind of

wood, and also divided by the area of the piece in inches, will give the extension also in inches. The extension of beams strained in the direction of their length being very small, this inquiry is of very little practical importance in the designing of framing.

On the STRENGTH *of a Beam to resist a Strain in the direction of its Length.*

79.—The strength to resist a weight that will produce fracture is as the sectional area of the beam subjected to a tensile strain. Consequently,

RULE II. To find the weight acting longitudinally that will tear a beam asunder, multiply the area of the section in inches, by the weight that will tear asunder a bar an inch square of the same kind of wood (S in Tables I. and II.), and the product will be the requisite weight in pounds; but the greatest constant load any piece should be allowed to sustain ought not to exceed one-fourth of this. The same rule applies to iron, and to the cohesion of timber when it is pulled asunder at right angles to the direction of the fibres.

The Tables I. and II. contain the results of the chief experiments that have been made on the direct strength. Table I. is compiled from various experiments described in Barlow's *Strength of Materials.** Table II. is taken from a *Treatise on Timber Trees* by T. Laslett, lately timber inspector to the Admiralty.

ON THE RESISTANCE TO CROSS STRAINS.

ON THE STIFFNESS OF BEAMS TO RESIST CROSS STRAINS.

80.—When a weight is laid upon the middle of a piece of timber which is supported only at the ends, it always bends more or less. When the weight bends the piece in a very small degree, the wood is said to be stiff; when the bending is considerable, it is called flexible.

The stiffness of beams, or their resistance to flexure, is inversely proportional to the space they are bent through by a given weight, when the lengths are the same: but that two pieces of different lengths may be equally stiff, the deflexion, or bending from the horizontal line, should be proportional to their lengths. For a deflexion of one-fourth of an inch in a joist 20 feet long would not be attended with any bad effect; but if a joist 4 feet long were to bend one-fourth of an inch, it would be totally unfit for its purpose. Hence the rules given by mathematical writers for determining the stiffness of beams, are not adapted to the carpenter's purpose; yet they are perfectly correct, on the principle of making the deflexion always the same, whatever the length may be; and the rules given in this work may be immediately derived from them, by making the deflexion proportional to the length, as it ought to be.

81.—NEUTRAL AXIS. If we fasten a beam firmly at one end and load it at the other, it is found to assume a curved form, so that the fibres in the lower part are shortened, and those in the upper part are lengthened; consequently the lower fibres are undergoing compression, and the upper ones extension. It will be evident that the fibres nearest the top will be more extended

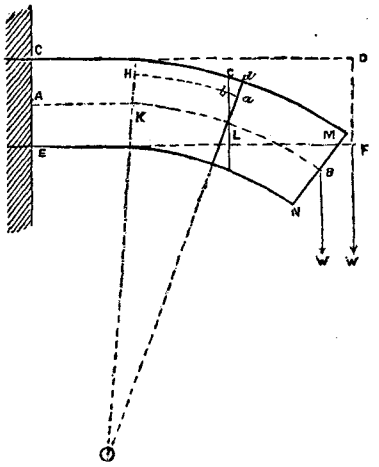
* Crosby Lockwood & Co.

than those lower down, while those nearest the bottom will be more compressed than the inner fibres. Consequently there must be a layer of fibres within the beam, at which extension ceases and compression begins, or in which there is neither extension nor compression; and this layer may therefore be called the *neutral surface* of the beam. A vertical section through the beam will cut the neutral surface in a straight line called the *neutral axis* of that section. It appears from experiments that when the strain upon a beam is less than would suffice to destroy its elasticity, this neutral axis may be considered to pass through the centre of gravity of the section.

In the case of a beam supported at its two ends and loaded in the middle so as to assume a curved form, the upper fibres, or those *above* the neutral axis, will be subjected to compression, and the lower ones, or those *below* the neutral axis, to extension.

82.—*To find the law of deflexion in a beam of rectangular section subjected to a transverse strain.* Suppose the beam CDEF (*fig.* 11) to be fixed horizontally at one end CE, and to be bent by a load W, acting at the other end DF, so as to assume the curved form CEMN. The fibres about the line CD will become longer than they were before the strain was applied, while those about the line EF will be shortened; but the neutral line AB, half-way between the other lines, will remain of the same length as before. Let K and L be two points taken near each other on the neutral line, OK and OL being the radius r of curvature of KL. Draw Lc parallel to OK, and let a represent the area of a fibre Hb at a distance Lb, which we will call x, from the neutral line; this fibre will be stretched the length ab by the strain produced by a portion of the force W, which we will call w. Then, since KL is equal to Hb the original length of this fibre, we have from (78)—

FIG. 11.



$$\frac{a\,b}{\mathrm{K\,L}} = \frac{w}{\mathrm{E}\,.\,a},$$

$$\text{and since } \frac{a\,b}{\mathrm{K\,L}} = \frac{\mathrm{L}\,b}{\mathrm{O\,L}} = \frac{x}{r}$$

$$\therefore w = \mathrm{E}\,.\,a\,\frac{x}{r}.$$

And the moment m of the force w about the neutral axis being $w\,.\,x$, we have

$$m = w\,.\,x = \frac{\mathrm{E}}{r}\,a\,x^2.$$

And the same relation holding good for all other fibres in the section, we have for the moment of resistance M of the whole section—

$$\begin{aligned}\mathrm{M} &= w\,x + w_1\,x_1 + w_2\,x_2 + \ \ldots \\ &= \frac{\mathrm{E}}{r}\,(a\,x^2 + a\,x_1^{\,2} + a\,x_2^{\,2} + \ \ldots) \\ &= \frac{\mathrm{E}}{r} \times \mathrm{I},\end{aligned}$$

where I is what is termed the *moment of inertia* of the section taken about the neutral

axis. The value of the moment of inertia in the case of a rectangle whose breadth is B and depth is D, taken about a line through its centre of gravity, is shown in treatises on mechanics to be

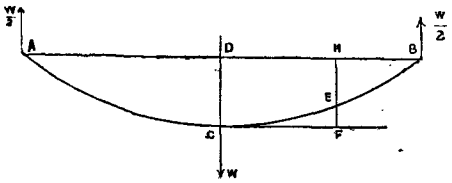
$$I = \frac{1}{12} B \cdot D^3.$$

If the section is a circular one, having B for the radius, we have

$$I = \frac{1}{4} \pi \cdot B^4.$$

83.—*The deflexion of a beam supported at each end and loaded in the middle.* Suppose AB (*fig.* 12) to represent the position of the neutral surface before the beam is loaded, ACB the curve it assumes after the load W is placed on the middle; then the deflexion will be the same as if the beam were fixed firmly at C and strained by weights $\frac{W}{2}$ acting at A and B in the opposite direction to that of W; so that the law of deflexion found in the last article will apply to this case. Let $CF = x$, $FE = y$, be the co-ordinates of the curve; δ the total deflexion DC at the middle, l the length AB. Then by (82) we have

FIG. 12.



$$\frac{1}{r} = \frac{M}{E \cdot I},$$

where M is the moment of strain about a section at E, and r the radius of curvature at E. Therefore we have

$$M = \frac{W}{2} \times BH = \frac{W}{2}\left(\frac{l}{2} - x\right).$$

Now it is shown in treatises on the differential calculus that when DC is very small as compared with AB, the value of the reciprocal of the radius of curvature is nearly

$$\frac{1}{r} = \frac{d^2y}{dx^2}, \text{ or } M = \frac{E \cdot I}{r},$$

$$\therefore E \cdot I \frac{d^2y}{dx^2} = \frac{W}{2}\left(\frac{l}{2} - x\right).$$

Integrating, we have

$$E \cdot I \frac{dy}{dx} = \frac{W}{2}\left(\frac{lx}{2} - \frac{x^2}{2}\right).$$

Integrating again, we get

$$E \cdot I \cdot y = \frac{W}{2}\left(\frac{lx^2}{4} - \frac{x^3}{6}\right),$$

which is the equation to the curve ACB.

To find the deflection δ at the middle point of the beam, we must put δ for y, and x equal $\frac{l}{2}$ in this equation, which gives

$$\delta = \frac{1}{48} \frac{W \cdot l^3}{E \cdot I}.$$

In the case of a rectangular beam whose depth is D and breadth B, we have $I = \frac{1}{12} B \cdot D^3$; therefore

$$\delta = \frac{W \cdot l^3}{4 E \cdot B \cdot D^3}.$$

If the beam has a circular section of which r is the radius, then $I = \frac{1}{4} \pi \cdot r^4$, where $\pi = 3{\cdot}1416$, and we have

$$\delta = \frac{W l^3}{12 E \cdot \pi \cdot r^4}$$

E being the *modulus of elasticity* as obtained by experiment, and the value of which for various kinds of wood is given in Tables I., II., X., and XVI., at the end of the Section. All the dimensions are supposed to be expressed in inches and the load W in lbs.

84.—*To find the relations of breadth to depth in the stiffest beam that can be cut out of a round tree.* Let r be the radius of the section of the tree, x the half-breadth of the beam, and y its half-depth; then since the *resistance to deflection* is inversely as the amount of deflexion, we have by the last article this resistance proportional to the breadth and the cube of the depth, when the length remains constant; therefore, $x y^3$ will be a maximum. And since $y^2 = r^2 - x^2$ in a circle, we have $x (r^2 - x^2)^{\frac{3}{2}}$ to be made a maximum; therefore, by the rules of maxima and minima we must have, $r^2 - 4x^2 = 0$, or $x = \frac{1}{2} r$;

$$\therefore y = \frac{\sqrt{3}}{2}, \text{ and } x : y = 1 : \sqrt{3} = 1 : 1{\cdot}732 = {\cdot}58 : 1,$$

which is, in general, a good proportion for beams which have to sustain a considerable load.

The geometrical construction of the figure of the stiffest beam is extremely simple. With the radius of the circle, step round its circumference, and having numbered the six points of division, those numbered 1, 2, 4, 5 will be the four angles of the parallelogram, which is the figure of the stiffest beam that can be cut out of a cylinder.

85.—*Resistance of beams to flexure when supported at both ends.* The deflexion of a beam by a given weight at the centre has been determined in Article 83, and as the *resistance* is inversely as the deflexion, it will be represented in a rectangular beam by

$$\frac{1}{\delta}, \text{ or } \frac{4 E \cdot B D^3}{W \cdot l^3}.$$

In practice it is essential that the deflexion should not be greater than one-fortieth of an inch for every foot length of beam, so that we can put the equation

$$\delta = \frac{W \cdot l^3}{4 E \cdot BD^3}$$

into the form,

$$\delta = \frac{W \cdot L^3 \cdot a}{40 BD^3},$$

where 12 L = l, and $a = \frac{17280}{E}$, and is a constant whose value we can determine experimentally by means of the equation,

$$a = \frac{40 \text{ B} \cdot \text{D}^3 \cdot \delta}{\text{W} \cdot \text{L}^3},$$

by which formula the values of a in Tables V., VI., VII., and VIII. have been computed; the length L being taken in *feet* and the other dimensions in *inches;* W being expressed in lbs.

86.—The quality of timber being the same, a beam will be stronger in proportion as its depth is greater; but there is a certain proportion between the depth and breadth which, if it be exceeded, the beam will be liable to overturn, and break sideways. To avoid which, the breadth should never be less than that given by the following rule, unless the beam be held in its position by some other means.

RULE III. Divide the length in feet by the square root of the depth in inches, and the quotient multiplied by the decimal 0·6 will give the least breadth that should be given to the beam.

When the depth is not determined by other circumstances, the nearer its form approaches to that determined by the rule, the stronger it will be; and, from the same rule, another is easily obtained which will show the advantage of making beams thin and deep.

87.—*To find the depth of a beam of given length.* Supposing that the deflexion is not to exceed one-fortieth of an inch to every foot of the length. We must put $\delta = \frac{\text{L}}{40}$, L being in feet and δ in inches. Also from Article 84 we have B = ·58 D; substituting these values of δ and B in the last equation we have

$$\delta = \frac{\text{L}}{40} = \frac{\text{W} \cdot \text{L}^3 \cdot a}{40 \times \cdot 58 \text{ D}^4}$$

$$\therefore \text{D}^2 = \text{L} \times \sqrt{\frac{\text{W} \cdot a}{\cdot 58}}.$$

And where the beam is inclined at an angle θ, we have

$$\text{D}^2 = \text{L} \times \sqrt{\frac{\text{W} \cdot a \cdot \cos. \theta}{\cdot 58}}.$$

EXPERIMENTAL DATA.

EXPERIMENTS ON OAK.

88.—Duhamel made some experiments on oak, where the scantlings were as large as they are generally used in buildings; and as the results of experiments on large pieces will be most highly valued by the generality of readers, we shall here describe as much of them as is applicable to the present purpose.

A piece of oak 9·6 inches deep and 10·66 inches in breadth, was placed upon two supports 24·5 feet apart, and a weight of 8,198 lbs. was suspended from the middle which bent it in the middle 3·73 inches. The piece broke with 9,613 lbs., but it was found to have been faulty. Hence the value of a by the formula in Art. 86 is

$$a = \frac{40\ \mathrm{B}\ .\ \mathrm{D}^3\ .\ \delta}{\mathrm{W}\ .\ \mathrm{L}^3} = 40\ \frac{10{\cdot}66\ (9{\cdot}6)^3\ 3{\cdot}73}{8198\ (24{\cdot}5)^3} = {\cdot}0114.$$

Another piece of oak, which was very sound and straight-grained, the depth 12·2 inches, the breadth 10·66 inches, and the bearing 24·5 feet, with a weight of 8,198 lbs., bent 2·65 inches. Whence $a = 0{\cdot}0157$. The piece broke with a weight equivalent to 19,666 lbs., applied to the middle.

A third piece of oak, which was sound and straight-grained, was tried; the depth was 13·83 inches, the breadth 12·8 inches, and the length 24·5 feet; and with a weight of 8,198 lbs. it bent an inch in the middle.* Therefore $a = 0{\cdot}011$.

These are the only experiments on oak made on a large scale, where the deflexion has been measured while the elasticity of the pieces remained perfect, excepting Girard's experiments. The Table V. contains the results of the author's own experiments on beams supported at the ends and loaded at the middle, together with a selection from other experimentalists.

RULES FOR THE STIFFNESS OF BEAMS.

89.—It has been stated (Art. 85) that $\frac{40\ \mathrm{B} \times \mathrm{D}^3 \times \delta}{\mathrm{L}^3\ \mathrm{W}} = a$; therefore when the deflection amounts to $\frac{1}{40}$ inch per foot, or $40 \times \delta = \mathrm{L}$, the formula becomes $\frac{\mathrm{B} \times \mathrm{D}^3}{\mathrm{L}^2\ \mathrm{W}} = a$; and the following rules are constructed accordingly. When the deflection is required to be less than is here assumed, then multiply the constant number a by some number that will reduce the deflection to the proposed degree; for instance, if the deflection should be only half of one-fortieth, multiply a by 2; if one-third of one-fortieth, multiply a by 3, &c. Also, if the deflection may be greater than one-fortieth per foot, divide a by 2, 3, or any number of times that the proposed deflection may exceed one-fortieth of an inch per foot.

By means of the experiments recorded in the tables at the end of the Section and the equations (Arts. 85 and 86), the scantling of a piece of timber may easily be determined: for the use of those who do not understand algebraic expressions, the rules are given at length below with examples.

90.—To find the scantling of a piece of timber that will sustain a given weight at the middle when supported at the ends in a horizontal position.

* *Mémoires de l'Académie des Sciences, Paris*, 1768, pp. 535—537.

Case 1.—When the Breadth is given.

RULE IV. Multiply the square of the length in feet by the weight in lbs., and this product by the value of a opposite the kind of wood in the tables (Table V., VI., or VII.). Divide the product by the breadth in inches, and the cube root of the quotient will be the depth required in inches. Or $D = \sqrt[3]{\frac{L^2 \times W \times a}{b}}$.

Example. A beam of Norway fir is wanted for a 24-feet bearing to support 900 lbs., and the breadth to be 6 inches; required the depth? Here $\frac{24 \times 24 \times 900 \times \cdot00957}{6} = 827$, and the cube root of 827 is 9·38, the depth required in inches.

Case 2.—When the Depth is given.

91.—RULE V. Multiply the square of the length in feet by the weight in lbs., and multiply this product by the value of a opposite the name of the kind of wood in Table V., VI., or VII. Divide the last product by the cube of the depth in inches, and the quotient will be the breadth in inches required. Or $b = \frac{L^2 \times W \times a}{D^3}$.

Example. The space for a beam of oak does not allow it to be deeper than 12 inches; to find the breadth so that it may support a weight of 4,000 lbs., the bearing being 16 feet. Here $\frac{16 \times 16 \times 4000 \times \cdot0164}{12 \times 12 \times 12} = 9\frac{3}{4}$ inches nearly, the breadth required.

92.—But, generally, neither the breadth nor depth is given: in this case it will be best to fix on some proportion which the breadth should have to the depth; for instance, suppose it to be convenient to make the breadth to the depth as 0·6 is to 1, then the rule would become as follows:—

RULE VI. Multiply the weight in lbs. by the value of a opposite the kind of wood in the foregoing tables (Table V., VI., or VII.); divide the product by 0·6, and extract the square root. Multiply this root by the length in feet, and extract the square root a second time, which will be the depth in inches required. The breadth is here equal to the depth multiplied by the decimal 0·6. It is obvious that any proportion of the breadth and depth may be obtained by merely changing the decimal 0·6 in the rule, $D = \sqrt{\left\{L \sqrt{\frac{W \times a}{0{\cdot}6}}\right\}}$.

Example. A beam of Riga fir is intended to bear a ton weight in the middle of its length, the bearing is 22 feet; what should be the dimensions of the beam? A ton is 2,240 lbs. Here $\frac{2240 \times \cdot011}{\cdot6} = 41{\cdot}066$; the square root of 41·066 is 6·4, nearly; therefore $6{\cdot}4 \times 22 = 140{\cdot}8$; and the square root of 140·8 is 11·86 inches, the depth required. And $11{\cdot}86 \times \cdot6 = 7{\cdot}116$ = the breadth.

93.—*When the beam is inclined the scantling will be found by either of the following rules:*—

RULE VII. Multiply together the weight in lbs., the *cosine* of the angle θ which the beam makes with the horizon, and the constant number a for the kind of wood; divide this product by 0·6, and extract the square root of the quotient. Multiply this root by the length

in feet, and extract the square root again, which will give the depth in inches; or $D = \sqrt{\left\{ L \sqrt{\frac{W \times \cos. \theta \times a}{0{\cdot}6}} \right\}}$.

Otherwise, let AB (*fig.* 22, *Plate* II.) be the beam, and BC a vertical line; then AC will be the horizontal distance between the points of support.

RULE VIII. Multiply together the weight in lbs., the length of the beam in feet, the horizontal distance between the supports in feet, and the constant number a for the kind of wood; divide this product by 0·6, and the fourth root of the quotient will give the depth in inches. According to either rule, the breadth is assumed to be equal to the depth multiplied by the decimal 0·6.

Example. Let the length of the beam be 20 feet, the horizontal distance between the points of support 16 feet, and the weight to be supported one ton, or 2,240 lbs., by a beam of Riga fir. Then $\frac{2240 \times 20 \times 16 \times {\cdot}011}{{\cdot}6} = 13141$; the fourth root of 13141 is $10\frac{3}{4}$, nearly, and $10\frac{3}{4} \times {\cdot}6 = 6\frac{1}{2}$, nearly; therefore the beam should be $10\frac{3}{4}$ inches by $6\frac{1}{2}$ inches.

WHEN THE BEAM IS FIXED AT BOTH ENDS AND LOADED IN THE MIDDLE.

94.—The strain upon a beam fixed at both ends has excited much attention, in consequence of a supposed difference between the result of theory and experiments. If it had been possible to fix a beam so that it should not have suffered extension beyond the point of fixing, the demonstrations of Emerson and Professor Robison would have been perfectly correct; but it is evident that the beam will be extended beyond the point of support, and the quantity of extension must depend on the mode of fixing. According to the experiments of Belidor, the strength of a beam fixed at both ends is to the strength of a beam only supported at the ends as 3 is to 2. M. Parent obtained nearly the same result. Mr. Barlow has also investigated this case in his *Treatise on the Strength of Materials*, and has shown that, both theoretically and practically, the strengths in the two cases are as 3 to 2. The stiffness will also be nearly in the same proportion.

But we cannot in practice fix the ends of a beam into a wall without endangering its stability; therefore, the determination of the stiffness of beams to suit such a case is not an object of much importance.

When, however, a long beam AB is laid over several points of support, as in *fig.* 33, *Plate* III., a case of very common occurrence in building, the strength of the intermediate parts is nearly doubled, or twice as much as when the beams are cut into short lengths. Hence the carpenter will see the importance of using bridging and ceiling joists, and purlins, and rafters, in considerable lengths, so that a joist may extend over several binding joists, purlins over several trusses, and a rafter over several purlins; also, by contriving so that the joinings shall not be opposite one another, a floor or roof may be made tolerably equal in strength. Hence, also, we see the importance of notching joists, purlins, and rafters over the supports, instead of framing them between. (See also Art. 50.)

ON THE STIFFNESS OF CYLINDERS SUPPORTED AT BOTH ENDS.

95.—When a solid cylinder is supported at both ends. Let D be the diameter of the cylinder, and L its length.

We have shown in Article 83 that the deflexion of a cylinder whose radius is r is

$$\delta = \frac{W \cdot l^3}{12\,E \cdot \pi \cdot r^4};$$

and since $r = \frac{D}{2}$, therefore $12\,r^4 = \frac{3}{4}\,D^4$, and the stiffness being inversely as the deflection, we have

$$\frac{1}{\delta} = \frac{3\,E \cdot \pi \cdot D^4}{4\,W \cdot l^3}.$$

Putting Δ for the deflection of its circumscribing rectangular prism whose breadth and depth are D, we have (Article 83)—

$$\frac{1}{\Delta} = \frac{4\,E \cdot D^4}{W \cdot l^3};$$

$$\therefore \frac{1}{\delta} : \frac{1}{\Delta} = \frac{3\,\pi}{4} : 4 = 1 : 1{\cdot}7.$$

Therefore, to find the stiffness of a solid cylinder, or rather the dimensions, so that it may be capable of supporting a given weight, and such that the deflection shall not exceed one-fortieth of an inch for each foot in length, we have the following rule:—

RULE IX. Multiply the value of a for the kind of wood from the Tables at the end of the Section by 1·7, and multiply this product by the weight in lbs. Then multiply the square root of the last product by the length in feet, and the square root of the product will be the diameter of the cylinder in inches; or, $D = \sqrt{\{L \sqrt{W.\,a \times 1{\cdot}7}\}}$.

Example. A solid cylinder of elm is intended to support 10 cwt. (or 1,120 lbs.), the length of bearing 10 feet; required the diameter? The constant number for elm being ·0212, by one of the experiments in Table VII.

In this case we have $1{\cdot}7 \times {\cdot}0212 \times 1120 = 40{\cdot}3648$, and the square root of 40·3648 is 6·35; therefore $10 \times 6{\cdot}35 = 63{\cdot}5$, of which the square root is 7·97, or nearly 8 inches, the diameter required.

Since the area of section of the cylinder is $\pi \frac{D^2}{4}$, and that of the prism is D^2, it follows from the above that the stiffness of the cylinder is to that of its circumscribing rectangular prism, as three times the bulk of the cylinder is to four times the bulk of the prism.

OF THE STIFFNESS OF BEAMS SUPPORTED AT BOTH ENDS, WHEN THE WEIGHT IS UNIFORMLY DIFFUSED OVER THE LENGTH.

96.—Where the weight is uniformly diffused over the length of the beam, the deflection does not increase in the same proportion as when it acts at one point. For where the weight is uniformly diffused it increases as the length, and the deflexion will be as the fourth power of the length; consequently, according to the definition of stiffness given in Art. 80, the stiffness will be as the cube of the length.

The stiffness of a beam uniformly loaded may be derived from the general proportion, BD^3 varies as L^3W.

This proportion applies to the case of the rafters and purlins of a roof, to ceiling joists, and binding joists which support ceilings only; but it does not apply to flooring joists, because their stiffness is measured by the resistance offered to a strain at one point: a timber floor might seem stiff enough to support a uniform load, and yet shake very much by the weight of a single person moving over it.

97.—The above method may be applied in cases where beams are similarly loaded, as in rafters, ceiling joists, &c.; but the following manner of determining the stiffness may be used in other cases.

If we suppose x and y to be the co-ordinates of any point E on the curve assumed by the neutral line when the beam is loaded with a weight W distributed over its length, then the *moment of strain* about any point E (*fig.* 12) is shown in Art. 46 to be

$$M = \frac{W}{2}\frac{HA \times HB}{AB} = \frac{W}{2l}\left(\frac{l^2}{4} - x^2\right).$$

But by Art. 83, we have

$$M = E \cdot I \frac{d^2y}{dx^2} = \frac{W}{2l}\left(\frac{l^2}{4} - x\right).$$

Integrating this equation, we get

$$E \cdot I \frac{dy}{dx} = \frac{W}{2l}\left(\frac{L^2 x}{4} - \frac{x^3}{3}\right).$$

Integrating again, we have

$$E \cdot I \cdot y = \frac{W}{2l}\left(\frac{L^2 x^2}{8} - \frac{x^4}{12}\right).$$

Putting $y = \Delta$ and $x = \frac{l}{2}$, we have

$$\Delta \cdot E \cdot I = \frac{5}{6}\frac{W \cdot l^3}{64},$$

$$\text{or} \qquad \Delta = \frac{5}{8}\frac{W \cdot l^3}{48\,E \cdot I}.$$

Now by Art. 83, $\delta = \frac{W \cdot l^3}{48\,E \cdot I}$ is the deflexion caused by the weight W suspended from the

middle of the beam. Hence it appears that if W be the weight that is uniformly distributed over a beam supported at both ends, then the deflexion produced by this weight uniformly distributed would be to the deflexion produced by the same weight collected in the middle of the length as 5 : 8, or as 0·625 : 1. Therefore, in the rules in Arts. 90, 91, 92, and 93, it is only necessary to employ the weight in lbs. multiplied by 0·625 instead of the whole weight, and the rest of the operation is the same as in those rules; therefore it will not be necessary to repeat them.

If we put δ for the deflexion when W is at the middle, Δ for the deflexion when the weight is uniformly distributed, $l = 12$ L, $w =$ the load per foot of length; then $W = w \,.\, L$,

$$\Delta = \frac{5}{8}\delta = \frac{5}{8}\frac{a \,.\, W \,.\, L^3}{40\ B \,.\, D^3} = \frac{\cdot 625\ a \,.\, w \,.\, L^4}{40\ B \,.\, D^3}.$$

And by Art. 87 we put $L = 40\ \Delta$, or $\Delta = \frac{L}{40}$, therefore we have

$$B \,.\, D^3 = \cdot 625\ a \,.\, w \,.\, L^3$$

as the equation from which to find B or D when the other quantities are given.

Thus when B is given, D is found from

$$D^3 = \cdot 625\ a \,.\, w \,.\, \frac{L^3}{B};$$

or, when D is given, B is obtained from the equation

$$B = \cdot 625\ a \,.\, w\, \frac{L^3}{D^3}.$$

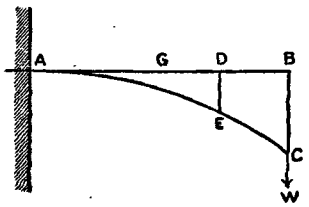
ON THE STIFFNESS OF BEAMS SUPPORTED AT ONE END.

98.—When a beam is fixed at one end, as in *fig.* 34, *Plate* III., the deflexion is much modified by the method of fixing; the deflexion being greater as the distance AC is greater; because the parts between A and C will be extended, and of course increase the deflexion. And as it is impossible to fix a bar so that it will not be extended beyond the point of support, there is much irregularity in the results of experiments on beams fixed in this manner.

To obtain the deflexion from theoretical considerations we proceed as in Art. 83, where it is shown that if r is the radius of curvature of the neutral line, then

$$M = E \,.\, I\, \frac{1}{r}.$$

FIG. 13.



Suppose AB (*fig.* 13) to be the neutral line of a beam of length l fixed at A and loaded at the outer end by the weight W, which causes the deflexion BC, and the line takes the curved form AEC. Let $AD = x$, $DE = y$, be the co-ordinates of the curve; then the moment of strain W about D is

$$M = W \times BD = W\,(l - x),$$

the deflexion BC being supposed to be very small as compared with the length AB. And since by the differential calculus

$$\frac{1}{r} = \frac{d^2y}{dx^2}, \text{ nearly,}$$

$$\therefore M = E \,.\, I \frac{1}{r} = E \,.\, I \frac{d^2y}{dx^2} = W\,(l - x).$$

Integrating, we have

$$E \,.\, I \frac{dy}{dx} = W\left(lx - \frac{x^2}{2}\right)$$

Integrating again, we find

$$E \,.\, I \,.\, y = W\left(\frac{lx^2}{2} - \frac{x^3}{6}\right),$$

which is the equation to the curve AEC.

Putting $y = \delta$, and $x = l$, and $I = \frac{1}{12} B \,.\, D^3$, we have

$$\delta = \frac{4\,W \,.\, l^3}{E \,.\, B \,.\, D^3}$$

all the dimensions being in inches.

Now in Art. 83 it was shown that the deflexion δ_1 of a beam supported at its ends and loaded in the middle was

$$\delta_1 = \frac{W \,.\, l^3}{4\,E \,.\, B \,.\, D^3} = \frac{1}{16} \cdot \frac{4\,W \,.\, l^3}{E \,.\, B \,.\, D^3} = \frac{\delta}{16}$$

Hence it appears that when we have two beams of equal dimensions, and the first is fixed at one end and loaded at the other, the second being supported at each end and loaded with the same weight in the middle, the deflexion in the former case is sixteen times as great as in the latter. We can therefore apply the formulæ and rules obtained for beams supported at each end (see Arts. 92, 93, 95) by using the constant $b = 16\,a$ for a in those rules. Or the value of b may be obtained independently from experiments described in Table VIII., at the end of the section.

99.—As beams fixed at one end are not frequently used in the construction of buildings, it will not be necessary to repeat the rules in words at length, but merely to give the formulæ—

When the beam is fixed in a horizontal position, $\left\{ L \times \left(\frac{b \times W}{0{\cdot}6}\right)^{\frac{1}{2}} \right\}^{\frac{1}{2}} = D.$

And $0{\cdot}6\ D = B.$

When the beam is inclined, and θ is the angle of inclination,

$$\left\{ L \times \left(\frac{b \times \cos.\,\theta \times W}{0{\cdot}6}\right)^{\frac{1}{2}} \right\}^{\frac{1}{2}} = D.$$

And $0{\cdot}6\ D = B.$

When a solid cylinder is fixed at one end, $\left\{ L \times (1{\cdot}7\ b \times W)^{\frac{1}{2}} \right\}^{\frac{1}{2}} = D.$

Where the value of b may be obtained from the table, and the deflexion is calculated to be one-fortieth of an inch per foot in length. B and D are to be expressed in inches, and L the length in feet.

WHEN THE WEIGHT IS UNIFORMLY DIFFUSED OVER THE LENGTH OF BEAMS FIXED AT ONE END.

100.—In this case we may suppose the whole weight W to act at the centre G of the beam AB (*fig.* 13), and the part of the weight between BD is $W \frac{BD}{AB}$, which acts at the middle point between B and D, and its lever arm about D is therefore $\frac{1}{2}$ BD; consequently the *moment of strain* about D or E is

$$M = W \frac{BD^2}{2\,AB} = W \frac{(l-x)^2}{2\,l} = \frac{E \,.\, I}{r};$$

$$\therefore E \,.\, I \frac{d^2y}{dx^2} = \frac{W}{2\,l}(l-x)^2.$$

Integrating, we have

$$E \,.\, I \frac{dy}{dx} = \frac{W}{2\,l} \frac{l^3 - (l-x)^3}{3}.$$

Integrating again,

$$E \,.\, I \,.\, y = \frac{W}{6\,l} \frac{l^3\,x + (l-x)^4 - l^4}{4},$$

$$\text{when } x = l,\ y = \delta, \text{ and } I = \frac{1}{12} BD^3,$$

$$\delta = \frac{3}{2} \frac{W\,l^3}{E \,.\, B \,.\, D^3}.$$

Comparing the deflexion in this case with that in which the weight W is at the end, as in Art. 98, we see that when the weight W is uniformly diffused over the length of the beam, the deflexion is to the deflexion of a beam loaded in the middle, as 3 : 8, or as ·375 : 1. Therefore, instead of W, in the above equations (Art. 99), substitute ·375 W, and the scantlings for beams uniformly loaded may be obtained.

ON THE STRENGTH OF BEAMS TO RESIST CROSS STRAINS.

101.—As it is often desirable to know the greatest weight a beam will bear without fracture, the following rules afford the means of obtaining it sufficiently near for practical purposes. The effect of deflexion is neglected, because it does not produce any material difference, unless the depth be very small and the length be considerable: a case which can rarely happen in the construction of buildings; it is further of importance to remark, that one-fifth of the breaking-weight causes the deflexion to increase with time, and finally produces a permanent set.

When a beam is subjected to a transverse strain, it has been shown (Art. 82) that the moment of strain at any section of which I is the moment of inertia and r the radius of curvature, is

$$M = \frac{E \,.\, I}{r}$$

Also, from Art. 78 we know that if S is the force per square inch of section which would produce the elongation *ab* (*fig.* 11) at a distance L $b = z$ from the neutral line, then

$$\frac{S}{E} = \frac{ab}{K\,L} = \frac{z}{r},$$
$$\text{or } \frac{S}{z} = \frac{E}{r}, \therefore M = \frac{S \cdot I}{z}.$$

By means of which formula we can find the strength or breaking-weight of a beam of any section, and loaded in any manner.

STRENGTH OF BEAMS SUPPORTED AT BOTH ENDS.

102.—Let the beam be loaded in the middle with a weight W, and be of rectangular section :—

First, let the side be vertical, then $I = \frac{1}{12} B \cdot D^3$, and, by Art. 46, $M = \frac{W}{4} l = \frac{S \cdot I}{z}$; and putting $z = \frac{1}{2} D$, we have (all the dimensions being in inches)—

$$\frac{1}{4} W\, l = \frac{S \cdot B \cdot D^2}{6},$$
$$\text{or } W = \frac{2}{3} S \frac{B \cdot D^2}{l} = \frac{B \cdot D^2 \cdot c}{L}, \text{ where L is the length in feet.}$$

Here c is a constant number to be obtained by experiment for each kind of wood from the equation, $c = \frac{W \cdot L}{B \cdot D^2}$, the values of which will be found in Table IX., at the end of the Section—

If the section is a square, or B = D, then

$$W = \frac{D^3 \cdot c}{L}.$$

Second, let the diagonal of the square section be vertical, then

$$z = \frac{\sqrt{2}}{2} D, \text{ and } \frac{I}{z} = \frac{\sqrt{2}}{12} D^3,$$
$$W = \frac{\sqrt{2}}{2} \cdot \tfrac{2}{3} S \frac{D^2}{l} = \frac{\sqrt{2}}{2} \frac{D^3 c}{L}$$
$$= \cdot 707 \frac{D^3 c}{L}.$$

Comparing this last equation with the previous one where the side was vertical, we see that the strength of the square beam strained in the direction of its diagonal is to that of the same beam strain in the direction of a side as ·707 : 1.

103.—The strength of a solid cylinder can be determined from the above formulæ, for in this case

$$\frac{I}{z} = \frac{\pi}{4}\frac{D^3}{8}, \therefore W = S\frac{\pi D^3}{8} = \frac{2}{3} S \frac{3\pi . D^3}{16 l} = \frac{3\pi}{16}\frac{D^3 . c}{L};$$

$$\text{or, } W = \frac{D^3 . c \times 0{\cdot}6}{L}.$$

If the cylinder is hollow, and d is the internal diameter, we have

$$\frac{I}{z} = \frac{\pi}{4} . \frac{D^4 - d^4}{8 D};$$

$$\therefore W = \frac{(D^4 - d^4) \times 0{\cdot}6\, c}{L . D}.$$

A hollow cylinder is both stronger and stiffer than a solid one containing the same quantity of matter; therefore, when it is desirable to combine strength and lightness, cylinders may be made hollow. In timber this is rather too expensive an operation to be often employed, but there are cases where it is useful. The strength of a tube, or hollow cylinder, is to the strength of a solid one as the difference between the fourth powers of the exterior and interior diameters of the tube, divided by the exterior diameter, is to the cube of the diameter of a solid cylinder: the quantity of matter in each being the same.

104.—*To find the strongest beam that can be cut out of a round tree.* Let r be the radius of the section, x the half-breadth, and y the half-depth of the beam; then since the strength is proportional to $x . y^2$, we have to find what value of x will make this quantity a maximum.

$$x . y^2 = x (r^2 - x^2) = r^2 x - x^3,$$

which is a maximum when its differential coefficient is zero; or when

$$r^2 - 3x^2 = 0, \text{ or } x = \frac{r}{\sqrt{3}},$$

which gives, $y = \sqrt{r^2 - x^2} = r\sqrt{\frac{2}{3}}$.

Therefore, $x : y = 1 : \sqrt{2} = 1 : 1{\cdot}414 = {\cdot}707 : 1,$

and the breadth of the beam is the diameter of the section multiplied by ·577. The breadth of a square beam cut from the same tree is the diameter multiplied by ·707, the strength of which is proportional to $\frac{r^3 . \sqrt{2}}{4}$. But the strength of the former beam is proportional to $\frac{r^3 . 2\sqrt{3}}{9}$, or it is stronger than the square beam in the proportion of 385 : 354, or nearly as 101 to 110. Therefore we obtain the following results:—the strongest beam that can be cut out of a round tree is that of which the depth is to the breadth as the square root of 2 is to 1; or nearly as 7 is to 5. And the strength of a square beam cut from the same cylinder, or round tree, is to the strength of the strongest beam nearly as 101 is to 110; but the square beam would contain more timber, nearly in the ratio of 5 to 4·714.

EXPERIMENTS ON THE STRENGTH OF BEAMS SUPPORTED AT BOTH ENDS.

105.—On this kind of strength the experiments are most numerous, and some of the most important are collected in Table IX., at the end of the Section. In this table, as in all the others, the author has endeavoured to collect experiments of such various kinds as best show the strength of wood under different circumstances. This is considered much preferable to taking mean results; and it will convey much more useful information to the reader. It will be seen, by consulting the authorities referred to, that the specimens from aged trees are much inferior in strength to those of mean age: and that the strength of green timber differs materially from that of seasoned, or dry. Also, that the strength is greater in those specimens which are the most heavy; but the increase of strength is not exactly proportional to the increase of specific gravity.

RULES FOR THE STRENGTH OF BEAMS SUPPORTED AT BOTH ENDS.

106.—To find the weight that would break a rectangular beam when applied at the middle of its length, the beam being supported at the ends.

RULE X. Multiply the breadth in inches by the square of the depth in inches; divide this product by the length in feet; then the quotient multiplied by the value of c in Table IX., corresponding to the kind of wood, will give the weight in lbs.

Example. The length of a girder of Riga fir between the supports is 21 feet, its depth is 14 inches, and breadth 12 inches. Find the weight that would break it when applied in the middle. Opposite Riga fir in the table we find $c = 530$; and $\frac{12 \times 44 \times 14 \times 530}{21} = 59{,}360$ lbs., or above 26 tons.

If a beam of the same scantling and length had been supported at one end only, one-fourth of the weight would have broken it.

107.—To find the weight that would break a solid cylinder when applied at the middle of its length, the cylinder being supported at the ends.

RULE XI. Find the value of c for the kind of wood in Table IX., and multiply it by ·6; multiply the product by the cube of the diameter in inches, and divide by the length in feet: the quotient will be the weight in lbs. that would break the cylinder.

Example. What weight would break a solid cylinder of ash, 12 feet long and 8 inches diameter? For ash the value of c is 635 in the table, therefore $\frac{\cdot 6 \times 635 \times 8 \times 8 \times 8}{12} = 16{,}256$ lbs.

108.—If the weight be uniformly diffused over the length of a beam, it will require to break it twice the weight that would break it when applied at the middle of its length, as shown in Arts. 45 and 48.

STRENGTH OF BEAMS SUPPORTED AT ONE END.

109.—The rules for beams supported or fixed at one end are precisely the same as those for beams supported at both ends, except that a different constant number must be used, viz., the constant *d* in Table X at the end of the Section; or the constant for beams supported at both ends must be divided by 4 (Arts. 45, 46.) And when the weight is uniformly diffused over the length, the beam will bear double the weight that would break it when applied in the middle.

RESISTANCE TO DETRUSION, OR CRUSHING ACROSS CLOSE TO A FIXED POINT.

110.—There is another kind of cross strain which requires particular attention, as the strength of framing often depends upon it: that is, when a body is crushed across close to the points of support. Dr. Thomas Young called the resistance to this kind of strain the resistance to *detrusion*, but it is now usual to call it resistance to *shearing*, when the strain acts across the grain.

According to the experiments of Professor Robison, this resistance appeared to be exactly proportional to the area of the section, and quite independent of its figure or position. Mr. Barlow has also made some experiments on this kind of resistance, from which it appears that when the force is parallel to the fibres, the strength of fir to resist detrusion is from 556 to 634 lbs. per square inch, or about one-twentieth of its cohesive power in the direction of the fibres. Mr. Bevan found the force required to tear a half-inch iron pin out of Scotch fir, when applied in the manner of a pin to a tenon in a mortise, was 976 lbs., the thickness of the wood being ·87 inches, and the distance of the centre of the pinhole from the end 1·05 inches; the lateral cohesion of the same wood was 562 lbs. per square inch. (See Table III., at the end of the Section.) We have great reason to believe that the resistance to *shearing* or being crushed across is, in all cases, equal, or very nearly equal, to the cohesive force of the body; and as in construction it is the lateral cohesion of timber that is usually exposed to a shearing or detruding force, we may conclude that the numbers given in Table III. will be sufficient, with those above stated, to assist the carpenter in proportioning the parts which have to support this strain.

111.—To give an example of the application, let AC (*fig.* 15, *Plate* II.) be the lower end of a principal rafter, and CB the tie-beam. Now it is evident, that if the part D should not be made sufficiently long to resist the thrust of the foot of the rafter, it would force off the abutment at the line *b*C. Let us, for the sake of simplicity, suppose there is not a tenon in the joint; then the horizontal thrust of the rafter in lbs. should be equal to the area of the surface in inches, which would be forced asunder in the case of fracture, multiplied by the resistance of a square inch in lbs. But, in practice, the strain should be only one-fourth of the cohesive force; therefore, to find the length *b*C we have the following rule:—

RULE XII. Divide four times the horizontal thrust, found as in Art. 40, by the

breadth or thickness of the beam in inches, multiplied into the cohesive force of a square inch in lbs., and the quotient will give the length bC in inches.

Example. Find the horizontal thrust of a rafter, or any other oblique beam, by the principles detailed in Section I. (Art. 40). Let us suppose this pressure is found to be 5,600 lbs., and let the thickness or breadth of the beam be 6 inches; also, when the beam is of fir, the lowest number for the cohesive force is, according to Mr. Barlow's experiments, 556 lbs. Then $\frac{4\times5600}{6\times556} = 6{\cdot}7$ inches, nearly, for the distance from b to C. If the beam had been oak, then the resistance of a square inch is 2,316 lbs., from Table III.; therefore $\frac{4\times5600}{6\times2316} = 1{\cdot}7$ inches, nearly. Further application of these principles will be found in the section on Joints and Scarfing, Section IX.

ON BENT TIMBER.

112.—Bent timber, although but seldom employed in the construction of houses, is largely used in ship-building. *Compass timber* is that which has grown naturally in a curved form, and is preferred to timber which has been bent by artificial means, when it can be procured in sufficient quantity and of the required shape. The scarcity, however, of this material renders it necessary to bend straight timber to the required shape by some such process as the following:—A fine saw-cut is made from one or both ends of the beam, about one-third of its length. It is then boiled for some hours, and afterwards placed in a machine and bent by means of screws to the required curve. It is then screw-bolted and is ready for use.

From experiments that have been tried upon timbers that have been boiled or steamed it does not appear that the strength is materially diminished, provided the process is not continued more than two or three hours. But if continued for a longer period the timber is considerably weakened. For fuller particulars on this subject, the reader is referred to Barlow's *Strength of Materials.*

ON THE RESISTANCE TO COMPRESSION.

113.—When a piece of timber is compressed in the direction of its length, it yields to the force in a different manner, according to the proportion between its length and the area of its cross section. For more convenient illustration, let us suppose the piece to be a cylinder; then if its length be greater than about eight times its diameter, the force will cause it to bend in the manner shown in *fig.* 35, *Plate* III.; and it will break at the middle of its length. But when the length of a wooden cylinder is less than about eight times its diameter, the piece will expand in the middle of its length, and split in several places. Materials less flexible than timber break in different ways when under compression in short lengths.

According to the experiments of Rondelet and others, it appears that when the height of a square post is less than about seven or eight times the size of its base, it cannot be bent by any pressure less than that which would crush it. The internal mechanism of the resisting forces, when timber yields by crushing, is not exactly understood, but it appears to be evidently different in timber from what it is in stone and other brittle materials. In timber the resistance to crushing is less than the cohesive or tensile force; in brittle bodies it is always greater than the cohesive force of the material: but it must not be imagined that the resistance to crushing is an exception to the laws of compression, because the resistance to extension, and that to compression, are both employed in opposing a force tending to crush the body when the body is of a flexible nature.

The resistance of short pieces of timber to crushing increases in the ratio of the area of its section. According to the experiments of Rondelet, made on cubes of an inch in length, it required from 5,000 to 6,000 lbs. per square inch to crush oak; and under this pressure its length was reduced more than one-third. To crush fir it required from 6,000 to 7,000 lbs. per square inch; and the length was reduced one-half.*

The experiments by George Rennie, published in the *Philosophical Transactions* for 1818, give results considerably lower than those of Rondelet. The following are the results of his experiments:—

Base 1 inch square, length 1 inch of elm was crushed by..... 1,284 lbs.
——————————— American pine..... 1,606 ——
——————————— white deal ..... 1,928 ——
——————————— English oak..... 3,860 ——
———————length 4 inches of ditto..... 5,147 ——
—— 3 inches square, length 6 to 9 inches African oak .....60,480 —— =
6,720 lbs. per square inch.†

114.—The load a short piece of timber will bear when pressed in the direction of its length, without risk of being crushed, may, when the pressure is exactly in the axis of the piece, be found by the following rule:—

RULE XIII. Multiply the area of the piece of timber, in inches, by the weight found capable of crushing a square inch of the same kind of wood (see the preceding experiments, and also Table XIII., at the end of the Section). Then one-fourth of the product will give the greatest load in lbs. that the piece could bear with safety.

Example. Required the weight that a piece of oak, 3 inches by 2 inches, would support with safety? Here the area is $3 \times 2 = 6$ inches; and by one of Rennie's experiments above referred to, an inch square of oak is crushed by 3,860 lbs. Consequently, $\frac{6 \times 3860}{4} = 5{,}790$ lbs., the weight required.

If the area which would support a given weight be required, divide four times the weight by the number of lbs. that would crush a square inch, and the quotient is the area in inches.

By comparing the rule for the resistance to flexure with that for the resistance to crushing,

* *L'Art de Bâtir.*

† This is the mean of two experiments made by Mr. A. H. Renton with Bramah's press.

it will be easy to determine the length when these rules give the same result. This comparison is important, because the strength of pieces shorter than this length must be calculated by the rules for the resistance to crushing; but all pieces longer than this length must be calculated by the rule for the resistance to flexure.

Let the force that would crush a square inch be represented by f, then by the preceding rule (Rule XIII.) $\frac{D \times B \times f}{4} = W$. Also by the equation in Art. 117, we have $\frac{D^3 \times B}{L^2 \times e} = W$. Hence, $\frac{D \times B \times f}{H} = \frac{D^3 \times B}{L^2 \times e}$, or $L^2 = \frac{4 D^2}{f \times e}$, and $L = 2 D \sqrt{\frac{1}{f \times e}}$.

From the experiments on crushing, it appears that f may be taken at 4,000 lbs. for either fir or oak; and according to Table XVI. the value of e is nearly the same for fir as it is for oak, viz., 0·0015. Putting these numbers in the equation

$$L = 2 D \sqrt{\frac{1}{f \times e}}, \text{ we have } L = 2 D \sqrt{\frac{1}{4000 \times 0{\cdot}0015}} = 0{\cdot}816 D, \text{ nearly:}$$

that is, the length in feet is 0·816 times the least thickness in inches, when the resistance to flexure and the resistance to crushing are equal. Or, what is the same thing, the length is nearly ten times the least thickness when the resistances are the same. Consequently, when the length of a pillar is greater than ten times the thickness, its strength must be determined by the rules given in Articles 124 to 129. When it is less than ten times the least thickness, the strength must be determined by Rule XIII. of this article.

115.—Hodgkinson's experiments on the resistance to crushing of cylinders of wood, 1 inch diameter and 2 inches long, flat at the ends, are given in Table XIII. The figures in the first column are for specimens moderately dry, while those in the second column are for specimens kept in a warm place for two months longer, after being turned. It was found that wet timber showed great weakness, being in some cases less than half as strong as dry timber. In the same table are also given the results of experiments by Mr. T. Laslett on cubes of wood.

In making use, however, of this table, it must be borne in mind that when a piece of timber is cut out of a tree, different parts of it will possess different degrees of strength. Thus the older wood near the centre will be much harder and stronger than that near the outside; the strength will also depend upon the age of the tree, older trees which have not begun to decay being generally tougher than younger ones. For these reasons the tabulated numbers can only be taken as giving an approximation to the relative strength of different kinds of wood, and are probably rather above the average strength.

ON THE RESISTANCE TO COMPRESSION AT THE JOINTS OF FRAMING.

116.—There is yet another kind of resistance to compression to be considered, viz., when the end of one piece is pressed against the side of another. The strength of the joints of framing depends in some degree on this kind of resistance; for unless the resistance at the joint be equal to the pressure, a degree of compression may take place that would produce considerable derangement in the framing, if not a total failure.

In order to obtain some information on this important point, the author made the following experiments: He prepared two pieces of good Memel fir, and placing the end of the one piece upon the side of the other, he loaded it successively with 800, 900, 1,000, 1,100, 1,200, and 1,300 lbs. upon a square inch, examining the effect of each trial; the impression was faint with 900 lbs., but became very distinct with 1,000 lbs.; therefore he considers that the pressure on the joints of timbers of yellow fir should never be greater than 1,000 lbs. per square inch. The position of the annual rings, however, makes a considerable difference, for in some other trials the impression was very distinct with 950 lbs.

English oak was next tried; with a load of 1,400 lbs. the impression appeared to be about the same as 1,000 lbs. produced in Memel fir; and there was less difference from varying the position of the rings.

It is obvious that the pressure on the joints must limit the rules for the resistance of beams compressed in the direction of their length, nearly in the same manner as in the last article; with this difference, that the area of the joint is seldom equal to the area of the section of the beam. But if B × D be the area of the section of the beam, the area of the joint may always be expressed by $n \times B \times D$. Consequently, $n \times B \times D \times F = \frac{B \times D^3}{L^2 \times e}$; and $L = D \sqrt{\frac{1}{n \times F \times e}}$, where F is the force which produces a sensible impression.

Hence it appears, that in fir the least thickness of the beam in inches multiplied by $10 \sqrt{\frac{1}{n}}$ is equal to the length in inches, when the resistance of the beam and that of the joint are equal; and $8{\cdot}3 \sqrt{\frac{1}{n}}$ multiplied by the breadth gives the length for oak framing.

Let the area of the joint be half the area of a section through the beam, then $n = \frac{1}{2}$ and $\sqrt{\frac{1}{n}} = \sqrt{2} = 1{\cdot}414$. Hence, when the area of the joint is in this proportion, in a fir frame, and the length is less than fourteen times the least thickness, the scantling must be regulated by the size of the joint instead of the resistance to flexure.

In order to prevent the ends of struts or posts from injuring the sides of the timbers against which they abut, cast-iron shoes or sockets are often placed on the ends, as shown in Section IX., by which means the pressure is distributed over a larger surface.

ON THE STRENGTH OF COLUMNS AND POSTS TO RESIST FLEXURE.

117.—It is known from experience that there is a certain force that will bend a piece of timber when acting in the direction of its length; and that, when it has been bent in a small degree, a still greater force is required to complete the fracture. But our investigation must be confined to the strength to resist the first degrees of flexure.

The strain will be directly as the weight or pressure, and inversely as the strength, which is inversely at the cube of the diameter. The strain will also be directly as the deflexion, which will be directly as the quantity of angular motion, and as the number of parts strained: that is, directly as the square of the length, and inversely as the diameter. Joining these proportions, and retaining the some notation as in the preceding investigations, we have $\frac{L^2 \times W}{D^4}$

is as the strain, and $1{\cdot}7\ e \times L^2 \times W = D^4$, e being a constant number for the same material; the strain being supposed constant.

When the post is rectangular, and D is the least side, then $e \times L^2 \times W = BD^3$.

If the post be square, it will break in the direction of its diagonal; and $4\ e \times L^2 \times W = D^4$; where D is the diagonal.

118.—The stiffest rectangular post is that in which the greater side is to the less as 10 to 6; therefore, when the post is insulated, this form should be preferred; but even when the the post is of this form it will bend in two directions. In this case the equation becomes $0{\cdot}6\ e \times L^2 \times W = D^4$; where D is the least side. The greater side will be found by dividing the lesser by ·6.

119.—When two inclined beams or rafters are strained by a weight resting upon the point where they meet, as in *fig.* 1, *Plate* I., the pressure in the direction of the beams may be found by Art. 9 of Section I.; and substituting this pressure for W, in one of the preceding equations, the scantlings may be found that would be capable of sustaining these pressures. And generally, let the pressure in the direction of a beam be found by the principles in Section I., then the pressure thus found being substituted for W in the equations, will enable the reader to find the scantlings that would support these pressures.

120.—In these equations the beams and columns have been supposed to be perfectly straight, and the pressure to be exactly in the direction of the axes; but it often happens that this cannot be the case; and as a very slight deviation causes a considerable difference in the magnitude of the strain, it is easy to account for the great irregularities which may be found in the few experiments that have been made on this strain.

Let AB, *fig.* 36, *Plate* III., represent a beam supporting a load at A, and supported itself at the point B. Join AB, and if the line does not pass through the centre C of the cross section of the post or beam at the middle of its length, the strain will be much increased, because the weight acts with the energy of a lever. The same thing happens when the beam is not perfectly straight, as in *fig.* 35.

When a beam or post, which is not straight, is pressed in the direction of its length, or where the pressure acts with a leverage, as in *fig.* 36, the effect of this leverage must be considered.

121.—A column or pillar that shall be equally strong throughout will be generated by the revolution of two parabolas round the axis of the column, the vertices of the curves being at the extremities, as is shown in *fig.* 37; for when all the other quantities are constant, $L^2 : D^4$, or $L : D^2$, a property of the parabola.

But the figure of a column depends on two conditions: the one, that it shall rest firmly on its base, and offer a solid bearing for the load to be supported; the other, that it shall be capable of the greatest degree of resistance. To fulfil the first condition, it should be a frustum of a cone; to fulfil the second, it should be of the form generated by the revolution of two parabolas: and combining the forms which fulfil these conditions, we produce nearly that form which has been adopted for columns—that is, a column with a slight swell in the middle. But where beauty rather than strength is the object, one that gradually diminishes from the base to the capital is preferred.

EXPERIMENTS ON THE STIFFNESS OF BEAMS TO RESIST COMPRESSION.

122.—The experiments are few on this strain; indeed, it is difficult to make such experiments without an expensive apparatus, and unless they are made with much care they are of little value. Tables XIV. to XVIII. contain the results of the most valuable for our present purpose. The weight that produced the first degree of deflexion, and the weight that broke the piece, are given in the tables; but that producing the first deflection is the one of the greatest importance.

Many of M. Girard's experiments were made with defective specimens; these are rejected, because pieces so defective should not be employed in any situation where they are exposed to much strain. By description and plates representing the most defective specimens, M. Girard has rendered it easy to ascertain the cause of many of the irregularities of his experiments. The least deflexion only, with the weight that produced it, is given for each piece in the above table; several other deflexions were observed, but the first is the only one that is of use for the purpose of determining the strength of posts or columns. Most of the specimens bent in the direction of the diagonal, consequently they were curved both in the direction of the breadth and thickness. The deflexion given above is that in the direction of the thickness, except in one case, which is last but two in Table XV.; in that case the force could not have been applied exactly in the direction of the axis.

Some of the pieces were broken; in those cases the weight that broke the piece is given. It is remarkable that the weight which broke the specimen is always about twice that which produced the first deflection, both in Girard's and Lamandé's experiments.

M. Girard has not described the state of the wood when his trials were made; but it appears from a remark he makes on the eighth experiment, that it had been cut about fifteen months; consequently, it would not be very dry, as might be inferred from the weight of the cubic foot given in the third column.

In the tenth column the effect of the greatest load that was tried is stated for some of the pieces. No. 1 recovered its first form after being loaded with 93,320 lbs. No. 2 retained a slight flexure, the greatest weight it bore being 68,946 lbs.

It is obvious that a column or post should not be loaded till the deflection becomes sensible; therefore the values of e, as found by these experiments, are too low for use. The constant number e should be taken of such a value as may give all the security that is necessary, without employing more timber than is consistent with just economy.

The highest value of e is 0·00125 in Lamandé's experiments (Table XIV.), and it is 0·00093 in Girard's. If the number be taken 0·0015 the result will always be sufficiently strong for use; for by employing the preceding rule the columns would seldom be loaded with above one-fourth of the weight that would produce sensible flexure.

123.—Experiments having been made upon oak only, it remains to determine the constant number e for other kinds of wood. It has been shown by Dr. Thomas Young that the weight W which would hold a beam in equilibrium, under a small degree of flexure, is expressed by $\frac{\cdot 8225\, d^2\, g}{l^2}$, where d is the least side, l the length, and g the weight of the *modulus of elasticity* corresponding to the area of the section; consequently, if E be the

weight of the modulus for a square inch (see Arts. 78 and 389), then $g = \mathrm{E}\, b\, d$, where b is the breadth: and the formula becomes

$$\frac{\cdot 8225\, b\, d^3\, \mathrm{E}}{l^2} = \mathrm{W};\ \text{or}\ \frac{\mathrm{W}\, l^2}{\cdot 8225\, \mathrm{E}} = b\, d.^3$$

According to experiments the modulus of elasticity of oak of a medium quality is 1,714,500 lbs.; and recollecting that in Dr. Young's formula l is in inches, we have

$$\frac{144\, \mathrm{W}\, l^2}{\cdot 8225 \times 1{,}714{,}500} = \mathrm{W}\, l^2 \times 0{\cdot}000102 = b\, d^3.$$

There is no doubt that from experiments made with dry oak of such a quality as that from which the weight of the modulus was obtained, and made with all the precision that might be employed on a small scale, the constant number given by this formula would agree with the experiments.

As the modulus of elasticity has been determined for several kinds of wood, Dr. Young's formula enables us at once to obtain the constant number for other woods, when that for one kind is obtained from experiments. Assuming, therefore, that 0·0015 is the proper constant number for oak, the Table XVI. will show those for other woods. The first column gives the kind of wood; the second its modulus of elasticity for a square inch in lbs. avoirdupois; and the third contains its constant number, to be employed in the rules for the strength of posts and columns.

In the oak and fir the constant numbers do not differ materially, but in small scantlings oak is more liable to warp; and besides, oak is seldom so straight-grained or so free from knots as yellow fir; therefore, it is usually employed in larger scantlings. But this must depend on the judgment of those who are to use it.

PRACTICAL RULES FOR THE STRENGTH OF COLUMNS, POSTS, AND OTHER BEAMS, PRESSED IN THE DIRECTIONS OF THEIR LENGTHS.

124.—To find the diameter of a column or pillar which will sustain a given weight, when the pressure is in the direction of the axis.

RULE XIV. Multiply the weight or pressure in lbs. by 1·7 times the value of e for the kind of wood, taken from Table XVI.; then multiply the square root of the product so obtained by the length or height in feet, and the square root of the last product will be the diameter required in inches.

If the column be shorter than ten times its diameter, then the proper diameter will be found by Rule XIII., Art. 114.

Example. Let it be required to support 12 tons (26,880 lbs.) by a cylindrical oak post, of which the height is 8 feet. Then, by the Table XVI., the value of e for oak is 0·0015; therefore, $26880 \times 1{\cdot}7 \times 0{\cdot}0015 = 68{\cdot}544$, of which the square root is 8·28, nearly. And $8{\cdot}28 \times 8 = 66{\cdot}24$; the square root of 66·24 is very nearly ·148; therefore 8·14 inches is the diameter required.

125.—To find the scantling of a rectangular post or beam capable of sustaining a given pressure in the direction of its length, and coinciding with the axis.

RULE XV. Multiply together the weight or pressure in lbs., the square of the length in feet, and the value of e for the kind of wood from Table XVI. Divide this product by the breadth in inches, and the cube root of the quotient will be the thickness in inches.

In this rule, as in the last, when the beam or post is shorter than ten times its thickness or least dimension, the scantling found by this rule is too small. The proper scantling in such cases may be found by Rule XIII., Art. 114, where the cause of this limitation is explained.

Example. Let the height of a post of Memel fir be 8 feet, its breadth 7 inches, and the weight to be supported 12 tons, or 26,880 lbs. The value of e by Table XVI. for Memel fir is 0·00133; therefore, $\frac{26880 \times 0{\cdot}00133 \times 8 \times 8}{7} = 327$, nearly; and the cube root of 327 is 6·889 inches, the thickness required.

126.—Sometimes the strain arises from the pressure produced by the position of the beams, as in *fig.* 1 or 3, *Plate* I.; in that case the pressure in the direction of the beam must be found by the rules in Section I., and this pressure must be substituted instead of the weight, observing that the pressure must be found in lbs.

HODGKINSON'S EXPERIMENTS ON LONG PILLARS.

127.—Some valuable experiments on the strength of long pillars of wood were made by the late Mr. Eaton Hodgkinson, and are recorded in the *Philosophical Transactions* for 1840. The results of these experiments on Dantzic oak and red deal will be found in Table XVII. To find n the power of the diameter, or of the side of a square, to which the strength is proportional; the length being constant, and the pillar so long as not to be crushed with the breaking weight. For this purpose Table XVII. will supply us with the results of six experiments on pillars of Dantzic oak, 46·1 inches long; whence it appears that a pillar 1·02 inches square was broken with a mean weight of 1,754 lbs., and one 1·5 inches square with 7,888 lbs.

Here we have

$$\frac{1{\cdot}5}{1{\cdot}02} = \frac{1{\cdot}47}{1};$$

$$\therefore 1^n : 1{\cdot}47^n = 1754 : 7888.$$

Reducing gives $n = 3{\cdot}902$; whence the strength is nearly as the fourth power of the side of the square. We therefore assume the strength of timber to be as $\frac{d^4}{l^2}$, which is the conclusion which Euler and other authors have arrived at from theoretical considerations. (See Art. 117.)

Whence if b is the breaking-weight and a a constant to be obtained by experiment for any particular kind of wood, we have the equation,

$$b = \frac{a \cdot d^4}{l^2}.$$

128.—The experiments in Table XVII., on square pillars of Dantzic oak flat at the ends, give as below:—First, from a mean of the results of four experiments, a pillar $60\frac{1}{2}$ inches or 5·04166 feet long, and 1·75 inches square, required 9,625 lbs. to break it; therefore taking the length in feet and the lateral dimensions in inches, we find from the above formula, $a = 26{,}085$ lbs. Second, from a mean of three experiments on pillars, 46·1 inches or 3·84166 feet long, and 1·5 inches square, we find $b = 7888$; from which we obtain $a = 22{,}999$ lbs. The mean value from these two being $a = 24{,}542$ lbs., or about 11 tons.

For red deal, from two experiments on pillars 4 feet 10 inches long, and 2 inches square, we obtain in the same way, $a = 17{,}511$ lbs., or about 8 tons.

In using the above formula, the length is to be expressed in feet, the other dimensions in inches, and the breaking-weight in lbs. or tons. The safe permanent load on a column should not exceed one-eighth of the breaking-weight; so that in practice we may use $a = \frac{5}{4}$ ton for oak, and $a = 1$ ton for fir.

STRENGTH OF SHORT PILLARS.

129.—When the length of a pillar is less than twenty-five times its diameter, but more than ten times, the resistance to *crushing* comes into action as well as the resistance to *bending*, the material being partly crushed before it breaks by bending. Mr. Hodgkinson's method of approximating to the strength of such pillars is, first to calculate the breaking-weight (b) by the formula for long pillars, as above, Art. 127; then if c is the area of the section of the pillar in inches multiplied by the crushing strength per square inch (as per Table XIII.), the breaking-weight (W) is found by the formula,

$$W = \frac{b \cdot c}{b + \frac{3}{4}c}.$$

Thus, in deal the crushing strength per square inch is about 3 tons, or between 6,000 lbs. to 7,000 lbs., and in oak 10,000 lbs., or $4\frac{1}{2}$ tons. Let us find, for example, the breaking-weight W of a pillar of oak 4 inches square, whose length is 5 feet, or fifteen times the diameter; then taking $a = 11$ tons, we have

$$b = a\frac{d^4}{l^2} = 11 \times \frac{256}{25} = 112{\cdot}6 \text{ tons.}$$

$$c = 16 \times 4{\cdot}5 = 72 \text{ tons.}$$

$$\therefore W = \frac{112{\cdot}6 \times 72}{112{\cdot}6 + 54} = 48{\cdot}7 \text{ tons.}$$

The *permanent safe load*, acting in the direction of the axis of the column, should not therefore exceed 6 tons, or one-eighth of the breaking-weight.

STRENGTH OF CURVED RIBS.

130.—When a curved rib is of the proper curve of equilibrium, and the load invariable, the stress is as the weight on any portion of the arch, which is as its length z, and it is to the strain as the length of the arc is to the radius of curvature; that is, making w the weight of a unit in length, then $z : r :: w z : r w =$ the strain in the direction of the curve. In this expression w is the stress on a unit in length of the curve at the vertex, and if that unit be 1 foot, then the radius of curvature r must be in feet.

But besides the constant load on a structure, a bridge for example, there are often strains caused by variable loads, such as heavy waggons and the like. The effect of such loads upon a continued rib is the next object of our inquiry.

Let ACB (*fig.* 27, *Plate* III.) be the rib, and let a load W be applied in the middle at C. The effect of such a load would be to depress the curve at C, and to cause it to rise at e; and f; dividing the curve into four equal parts. Denoting the length of each part by l, then 2 DC : AC : : W : the pressure in the direction AC; or pressure $= \frac{\text{W} \times \text{AC}}{2\,\text{DC}}$; and $e \times 8\,l^3 \times \frac{\text{W} \times \text{AC}}{2\,\text{DC}} \times \text{sine } e\,\text{C}\,a = \text{BD}^3$,

$$\text{or } 2\,l \times \left(\frac{e \times \text{W} \times \text{AC} \times \text{sin. } e\,\text{C}\,a}{\text{B} \times 2\,\text{DC}}\right)^{\frac{1}{3}} = \text{D}.$$

But here it may be observed, that no notice is taken of the resistance at C, because it is not possible to join large pieces so as to make them equally as strong as a solid beam of one piece; therefore, to keep the rule as simple as possible, the strength at C has been taken to compensate for the defects of a built rib.

But the strain upon the rib will not be the greatest when the weight is applied in the middle. The exact point where the strain is greatest has not been ascertained, but it will be near enough for practice to fix this point at the distance of one-third of the span from one of the abutments.

131.—In the case of a load supported by a curved rib of the proper form for its parts to be in equilibrium, if r be its radius of curvature at the flattest point in feet, and w the load on a superficial foot at the summit, then (from Arts. 114 and 130) $\frac{\text{B}\,w\,r}{12} = \frac{\text{B}\cdot\text{D}\,f}{4}$; or the breadth of the load being equal to that of the beam or rib, then $\frac{w\,r}{3\,f} = \text{D}$. Hence the following rule:—

Multiply the load on a square foot at the summit in lbs. by the radius of curvature in feet; then the product being divided by three times the force it requires to crush a square inch, the quotient will be the depth of the rib in inches; the breadth being the same as the breadth of the load.

PRACTICAL RULE AND EXAMPLE.

132.—Let the weight be considered to act at E, *fig.* 27, then (by Art. 9, Sect. 1) if the weight be represented by EF, the pressure in the direction EA will be represented by EB.

Or, EF : EA : : W : pressure. Taking an example in numbers, let EF be 77 feet, and EA 135, W being 50,000 lbs. Then 77 : 135 : : 50,000 : 87,662 lbs., the pressure required.

RULE XVI. To find the scantling of the rib. Multiply together the pressure in lbs., the constant *e* from Table XVI. and the *sine* of the angle *dEh*; then divide the product by the breadth in inches of all the ribs the weight will bear upon; the cube root of the quotient multiplied by the distance AE, in feet, will give the depth of the rib in inches.

Example. In a bridge of 200 feet span, consisting of 3 ribs, each 24 inches, or the whole breadth of the ribs 72 inches; required the depth. The *sine dEh* = 0·1, and the constant number from Table XVI., corresponding to oak = 0·0015. The pressure in the direction EA being 87,662 lbs. as above found. Then $\frac{87662 \times \cdot0015 \times 0\cdot1}{72} = 0\cdot18263$. The cube root of 0·18263 is 0·567, nearly; and the distance AC is nearly 135. Therefore, 0·567 × 135 = 76·5 inches, the depth required.

STRENGTH OF STORY-POSTS.

133.—It has already been stated, that the stiffest rectangular post or beam is that of which the sides are to one another as 10 to 6 (see Art. 118); the rule expressed in words at length may be useful:—

RULE. Multiply the weight or pressure in lbs. by 0·6 times the tabular number *e* for the kind of wood, from Table XVI. Extract the square root of this product, and multiply the root by the length in feet. The square root of the last product will be the lesser side in inches.

Divide the lesser side by 0·6, and the quotient will give the greater side.

Example. It is required to support a part of a wall by an oak post, 11 feet in length. The wall to be supported contains a rod of reduced brickwork which weighs 13 tons, or 29,120 lbs.; and it is proposed to determine the scantling of the post so as to be sufficient to sustain the pressure. According to the rule 29120 × 0·6 × 0·0015 = 26·208. The square root of 26·208 is nearly 5·11; and 5·11 × 11 = 56·2. The square root of 56·2 is 7·49; consequently, the lesser side of the post should be 7·42 inches. And $\frac{7\cdot49}{0\cdot6} = 12\cdot48$ inches, the greater side; therefore, a post 11 feet long, of which the scantling is $12\frac{1}{2}$ inches by $7\frac{1}{2}$ inches, would support a rod of brickwork with safety.

A post that sustains a considerable burden should never be exposed to a cross strain; as a very small force of this kind has a considerable effect when the post is compressed in the direction of its length.

Tables of the scantlings of story-posts are given at the end of this Section, Tables XIX. to XXII.; but story-posts depend so much on the nature of the building to be supported, that it would be difficult to reduce them to particular rules; it will not, however, be difficult to estimate, with sufficient accuracy, the weight a post of this kind may have to support, and then the scantling will be found by the preceding rules.

ON THE RESILIENCE OF TIMBER.

134.—Resilience, or the power of resisting the impulse of a body in motion, is a species of strength which it is of importance to consider, as it is well known that bodies which will resist a very great pressure may be fractured by the stroke of a hammer moving with a moderate velocity. The general principles of resistance to impulse, and their application to metals, have been considered very fully in Tredgold's *Essay on the Strength of Iron.* It is there shown, that if w be the weight of a falling body, h the height of its fall, P the elastic force of the material at the flexure s, and W the weight of the piece, then it requires to produce any other degree of flexure x by impulse, that

$$2\,h\,w^2 = \frac{\mathrm{P}\,x^2}{s}\,(\mathrm{W} + w).$$

To show the agreement of the investigation with experiment, we may compare the experiments made by Mr. Bevan, in 1825. A bar supported at the ends, the distance of the supports being 18 feet, the weight of the bar itself 127 lbs., being equivalent to 63·5 lbs., collected at the middle, and the weight which bent it 1 inch in the middle 148 lbs. The weight of the falling body was 28 lbs.; hence from these data we have

$$\sqrt{\left(\frac{2\,h\,w^2\,s}{\mathrm{P}\,(\mathrm{W} + w)}\right)} = x = \sqrt{\left(\frac{2\,h \times 28 \times 1}{148\,(63{\cdot}5 + 28)}\right)} = {\cdot}34\,\sqrt{h}:$$

that is, in this case the square root of the height of the fall in inches, multiplied by ·34, ought to be equal to the depression in inches; and the table below shows the comparison.

Height of fall.	Depression by experiment.	Depression by formula.
12 in.	1·25 in.	1·18 in.
24 —	1·66 —	1·66 —
36 —	2·35 —	2·04 —
48 —	2·62 —	2·35 —

Since, by the preceding rules of this section, the weight may be found which produces a given depression, and as the mass of the resisting body may be readily ascertained, it becomes easy to compute the strength which will resist any percussive force for any particular case; but general rules are not so easily drawn, in consequence of the mass, as well as the strength of the resisting body, being concerned in the inquiry.

TABLE I.—*Tensile Strength of Different Woods.*

Kind of Wood.	Specific gravity.	Modulus E of elasticity.	Cohesion S per square inch.
		lbs.	lbs.
Ash, English	·738	1,467,000	17,200
Beech	·696	1,353,630	11,470
Birch, common	·711	1,353,600	...
„ American	·650	1,477,000	...
Box	·983	1,800,000	19,900
Bullet tree (Berbice)	1·029	2,628,700	...
Cabacally „	·900	1,845,200	...
Cedar	·540	...	4,880
Chesnut, Spanish	·610	...	10,500
Deal, Christiania	·689	1,564,800	...
„ Memel	·590	1,591,000	...
Elm, English	·548	719,800	14,000
Fir, New England	·553	2,191,200	...
„ Riga	·746	1,159,600	12,200
„ Mar forest	·697	794,900	...
Greenheart (Berbice)	1·000	2,656,100	...
Larch	·542	904,900	9,000
Locust (Berbice)	·954	2,342,800	20,100
Mahogany	·637	1,400,000	8,000
Norway spar	·577	1,457,600	7,300
Oak, African	·983	2,302,100	21,000
„ Adriatic	·993	974,400	...
„ Dantzic	·756	1,191,200	...
„ English	·948	1,172,000	10,400
Pear	·646	...	9,800
Pine, pitch	·660	1,225,600	7,800
„ red	·657	1,840,000	...
Poplar	·360	...	5,500
Teak, Indian	·745	2,414,400	15,090
Tonquin bean (Berbice) ...	1·058	2,656,100	...
Walnut	·590	...	8,000

TABLE II.—*Tensile and Transverse Strength of Different Woods.**

Kind of Wood.	Modulus E of elasticity.	Values of *a*.	Cohesion S per square inch.	Values of *c*.
	lbs.		lbs.	
Ash, English	2,292,400	·0075	3,780	754
„ Canadian	1,375,920	·0125	5,600	558
Cedar (Cuba)	1,798,840	·0096	2,870	490
Elm, English	1,003,280	·0172	5,460	344
„ Canadian	2,474,200	·0171	9,180	805
Fir, Dantzic	1,737,570	·0070	3,230	767
„ Riga	3,009,680	·0051	4,050	525
Greenheart	1,747,520	·0098	8,820	1166
Larch, Russian	2,596,520	·0067	4,200	548
Mahogany, Spanish ...	3,084,120	·0056	3,790	749
„ Honduras ...	1,970,200	·0088	3,000	702
Oak, African	1,641,720	·0105	7,050	970
„ American white ...	2,144,600	·0080	7,020	703
„ „ live ...	2,812,920	·0062	3,830	632
„ Dutch...	1,106,200	·0156	...	576
„ English	1,545,600	·0112	7,570	705
„ Dantzic	...	...	...	414
„ French	2,480,880	·0070	8,100	747
„ Italian	1,527,740	·0113	...	737
„ Spanish	956,760	·0181	...	491
Pine, pitch	3,020,940	·0057	4,670	769
„ red (Canada)... ...	2,355,600	·0073	2,710	572
„ yellow (Canada)	from 1,236,960 to 3,611,800	·0140 to ·0048	2,030	471
Spruce (Canada)	3,087,200	·0056	3,930	586
Teak, Indian	2,123,880	·0081	3,300	768

TABLE III.—*Cohesion of a Square Inch pulled asunder in a Direction perpendicular to the Length of the Fibres.*

Kind of Wood.	Cohesion of a square inch perpendicular to fibres, in lbs.	Experimentalist.
Oak	2,316	Tredgold
Poplar	1,782	Idem.
Larch	from 970 to 1,700	Idem.
Memel fir ...	540 to 840	Bevan.
Scotch fir ...	562	Idem.

Emerson states that tough wood, such as elm and ash, is from 7 to 8, and even 10 times weaker across the grain than when strained in the direction of the fibres; and that straight-grained woods, such as fir, are from 16 to 20 times weaker than in the length of the fibres. The experiments of Barlow show that the strength of the lateral adhesion of the fibres in fir is about equal to 600 lbs. on a square inch, or one-twentieth of the direct cohesion.†

* The numbers in this Table have been deduced from the experiments described in Laslett's *Timber and Timber Trees*.

† Barlow's *Treatise on the Strength of Materials*.

TABLE IV.—*Cohesive Force of Iron.*

Kind of Iron.	Cohesion of a square inch in lbs.	Experimentalist.
Ironwire ...	113,077	Sickengen.
Ditto	93,964	Telford.
Swedish iron ...	78,850	Muschenbroek.
Ditto	72,064	Rennie.
Ditto	64,960	Telford.
Ditto	53,244	Brown.
German iron ...	69,133	Muschenbroek.
English iron { from / to	66,000 / 55,000	Rumford.
Ditto	61,600	Telford.
Ditto	56,000	Barlow.

Kind of Iron.	Cohesion of a square inch in lbs.	Experimentalist.
English iron ...	55,772	Rennie.
Welsh iron ...	64,960	Telford.
Ditto	55,776	Brown.
French iron ...	61,041	Perronet.
Russian iron ...	59,472	Brown.
Cast iron ...	68,295	Muschenbroek.
Do. spec. gravity 7·716	32,700	Bevan.
Ditto	19,488	Rennie.
Ditto, Welsh ...	16,255	Brown.
Ditto, average	16,505	Hodgkinson.

The cohesive force of different kinds of iron is shown in the above table, which will be of service in finding the dimensions of straps, &c. The load upon a square inch, either of wood or iron, should not exceed one-fourth of the weight that would produce fracture.

TABLE V.—*Experiments on the Stiffness of Oak Beams supported at both ends.*

Kind of Oak.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of *a*.	Authorities.
Old ship timber ...	·872	2·5	1	1	0·5	127	·00998	Tredgold.
Oak from young tree, King's Langley, Herts ...	·863	2	1	1	0·5	237	·0105	Idem.
Oak from Beaulieu, Hants ...	·616	2·5	1	1	0·5	78	·0164	Idem.
Ditto, another specimen ...	·736	2·5	1	1	0·5	65	·0197	Idem.
Oak from old tree ...	·625	2	1	1	0·5	103	·024	Idem.
Oak from Riga ...	·688	2	1	1	0·5	233	·0107	Idem.
English oak	·960	7	2	2	1·275	200	·0119	Barlow.
Canadian oak ...	·867	7	2	2	1·07	225	·009	Idem.
Dantzic oak	·787	7	2	2	1·26	200	·0105	Idem.
Adriatic oak... ...	·948	7	2	2	1·55	150	·0193	Idem.

TABLE V.—*continued.*

Kind of Oak.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of *a*.	Authorities.
English oak	·748	2 ·5	1	1	0 ·5	137	·00934	Ebbels.
Ditto, green	·763	2 ·5	1	1	0 ·5	96	·0133	Idem.
Dantzic oak, seasoned	·755	2 ·5	1	1	0 ·5	148	·0087	Tredgold.
Oak, seasoned ...	...	12 ·8	3 ·19	3 ·19	1 ·06	268	·008	Aubry.
					4 ·25	803	·0105	
Oak, green	...	6 ·87	5 ·3	5 ·3	·433	7,587	·005	Buffon.
Ditto	...	23 ·58	5 ·3	5 ·3	2 ·7	706	·0095	Idem.
Oak	...	8 ·52	5 ·06	6 ·22	0 ·709	4,146	·0133	Girard.
Oak (*bois du brin**)	...	16 ·86	10 ·66	11 ·73	0 ·67	4,559	·0213	Idem.
Oak (*quercus sesiliflora*) ...	807	2	1	1	0 ·35	149	·0117	Tredgold.
Oak (*quercus robur*†)	·879	2	1	1	0 ·35	167	·0104	Idem.

Oak from the Royal Forests.	Specific gravity.	Length in inches.	Breadth in inches.	Depth in inches.	Depression increased with time when loaded to this degree.		At the first fracture.		Values of *a*.	Values of *c*.
Name of Forest.					Load in lbs.	Deflexion in inches.	Load in lbs.	Deflexion in inches.		
High Meadow Forest ...	·7926	22	·97	·96	80	0 ·25	400	2 ·9	·0175	826
Ditto	·7563	22	·95	·95	60	0 ·162	390	2 ·4	·0143	835
Parkhurst Forest (sawn) ...	·8770	22	·98	·95	90	0 ·235	370	2 ·6	·0138	770
Dean Forest ...	·747	22	·95	·95	70	0 ·18	340	1 ·15	·0137	730
Ditto	·799	22	·97	·97	80	0 ·155	410	1 ·45	·0112	820
New Forest (cleft)	·822	22	1 ·0	1 ·0	70	0 ·21	410	4 ·0‡	·0195	751
Ditto (sawn) ...	·723	22	1 ·0	1 ·0	80	0 ·112	415	1 ·35	·0091	760
Bere Forest (sawn)	·714	22	1 ·0	1 ·0	70	0 ·155	360	1 ·15	·0142	660
Ditto	·732	22	1 ·0	1 ·0	70	0 ·1	477	1 ·5	·0093	875
Ditto	·839	22	1 ·0	1 ·0	80	0 ·14	380	1 ·1	·0113	698
								Means	·0134	773

* "*Bois du brin*," timber the whole size of the tree, except that which was taken off to render it square.

† See Section X., Art. 396, where the characters of these species are described.

‡ Slipped through between the supports, and retained a curvature of 2·1 inches, which was found to have decreased to 1·75 inches about twenty-four hours afterwards. The author has in another place noticed the advantage split timber possesses in respect of strength (Art. 385).

At an average the deflexion began to increase with the time when the load was about one-fifth of the breaking-weight, and the piece retained a permanent set; the deflexion is that which the piece took after the load had been at least twelve hours upon it. The specimens are all of very good quality: they were selected as the average qualities of the forests, and were procured for the purpose of making these experiments.

TABLE VI.—*Experiments on the Stiffness of Fir Beams supported at both ends.*

Kind of Fir.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of a.	Authorities.
Riga yellow fir, medium ...	...	18	2	7	0·25	103	·0115	Tredgold.
Yellow fir, from Long Sound, Norway	·6398	2	1	1	0·5	261	·00957	Idem.
Yellow fir, Riga	·480	2·5	1	1	0·5	123	·0102	Idem.
	·464	2·5	1	1	0·5	116	·011	Ebbels.
Ditto Memel, medium ...	·553	2·5	1	1	0·5	143	·0089	Tredgold.
	·544	2·5	1	1	0·5	145	·0088	
American pine, supposed to be the Weymouth pine	·460	2	1	1	0·5	237	·0105	Idem.
	·407	3	1	1	0·5	169	·0112	
White spruce, Christiana ...	·512	2	1	1	0·5	261	·00957	Idem.
White spruce, Quebec	·4650	2	1	1	0·5	180	·0138	Idem.
Larch, Blair, Scotland, dry... ...	·622	2·5	1	1	0·5	93	·0137	Idem.
Larch, seasoned, medium	·644	2·5	1	1	0·5	101	·0126	Idem.
	·554	2·5	1	1	0·5	112	·0111	Ebbels.
Larch, very young wood	·396	2·5	1	1	0·5	45	·0284	Tredgold.
Scotch fir*	·529	2·5	1	1	0·5	89	·01437	Idem.
Spruce fir, British ...	·555	2·5	1	1	0·5	103	·0124	Ebbels.
Fir (*bois du brin*) ...	...	21·3	10·48	10·48	1·02	4,389	·0115	Girard.
Ditto	...	10·65	10·48	10·48	0·2245	4,122	·022	Idem.
Cowrie	·579	4	3	3	0·29	1,680	·0088	Fincham.
Red pine	·544	4	3	3	0·36	1,680	·0109	Idem.
Yellow pine	·439	4	3	3	0·37	1,680	·0112	Idem.

* The tree from which this specimen was taken was grown in Buckinghamshire.

TABLE VII.—*Experiments on the Stiffness of Beams of Various Woods supported at both ends.*

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of *a*.	Authorities.
Ash from young tree, white coloured ...	·811	2·5	1	1	0·5	141	·009	Tredgold.
Ash from old tree, red coloured ...	·753	2·5	1	1	0·5	113	·0113	Idem.
Ash, medium quality	·690	2·5	1	1	0·5	78·5	·0163	Ebbels.
Ash	·760	7	2	2	1·27	225	·0105	Barlow.
Beech...	·688	7	2	2	1·025	150	·01277	Idem.
Teak	·744	7	2	2	1·276	300	·0076	Idem.
Poona (top)	·632	4	3	3	0·32	1,680	·0097	Fincham.
,, (butt)... ...	·658	4	3	3	0·25	1,680	·0076	Idem.
Elm	·540	7	2	2	1·42	125	·0212	Barlow.
	·544	2·5	1	1	0·5	99·5	·0128	Ebbels.
Cedar of Lebanon ...	·486	2·5	1	1	0·5	36	·0355	Tredgold.
Maple, common ...	·625	2·5	1	1	0·5	65	·0197	Idem.
Abele...	·511	2·5	1	1	0·5	84	·0152	Idem.
Willow	·405	2·5	1	1	0·5	41	·031	Idem.
Horse chestnut ...	·483	2·5	1	1	0·5	79	·0162	Idem.
Lime tree	·483	2·5	1	1	0·5	84	·0152	Idem.
Walnut, green ...	·920	2·5	1	1	0·5	62	·020	Ebbels.
Spanish chestnut, green ...	·875	2·5	1	1	0·5	68·5	·0187	Idem.
Acacia, green ...	·820	2·5	1	1	0·5	125	·0102	Idem.
Plane, dry	·648	2·5	1	1	0·5	99·5	·0128	Idem.
Alder, ditto	·555	2·5	1	1	0·5	80·5	·0159	Idem.
Birch, ditto	·720	2·5	1	1	0·5	90·5	·0141	Idem.
Beech, ditto	·690	2·5	1	1	0·5	97·5	·0131	Idem.
Wych elm, green ...	·763	2·5	1	1	0·5	92	·014	Idem.
Lombardy poplar, dry	·374	2·5	1	1	0·5	56·5	·0224	Idem.
Honduras mahogany	·560	2·5	1	1	0·5	118	·0109	Tredgold.
Spanish ditto ...	·853	2·5	1	1	0·5	93	·0137	Idem.
Sycamore	·590	2·5	1	1	0·5	76	·0168	Ebbels.
Pear tree, green ...	·792	2·5	1	1	0·5	59·5	·0215	Idem.
Cherry tree, green ...	·690	2·5	1	1	0·5	92·5	·0138	Idem.

A Table of Experiments on Metals may occasionally be useful.

Kind of Metal.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion in inches.	Weight in lbs.	Values of *a*.	Authorities.
Iron, malleable, Swedish ...	...	5·5	1	1	0·125	58	·00051	Tredgold.
Iron, malleable, English ...	7·62	5·5	1	1	0·15	58	·00062	Idem.
Ditto, cast	7·21	6·5	1½	3	0·75	440	·001	Idem.

TABLE VIII.—*Barlow's Experiments on the Strength and Stiffness of Beams supported at both ends. Length 7 feet, Scantling 2 inches × 2 inches.**

Kind of Wood.	Specific gravity.	Greatest weight and deflexion while elasticity remained perfect.		Breaking-weight.	Ultimate deflexion.	Values of *c*.	Values of *a*.
		Weight.	Deflexion.				
		lbs.	ins.	lbs.	ins.		
Ash	·760	225	1·27	772	8·92	675	·01050
Beech	·696	150	1·03	593	5·73	519	·01277
Elm	·553	125	1·69	386	6·93	338	·02469
Fir, New England ...	·553	150	·93	420	4·66	367	·00790
„ Mar forest ...	·696	125	1·44	436	6·00	381	·02174
„ Riga	·753	125	·87	422	6·00	369	·01456
Larch...	·531	125	1·89	325	8·58	284	·01910
Oak, Adriatic ...	·993	150	1·43	526	5·73	461	·01770
„ Canadian ...	·872	225	1·08	673	6·00	589	·00806
„ Dantzic ...	·756	200	1·59	560	4·86	486	·01451
„ English ...	·934	200	1·28	637	8·10	557	·01190
Pine, pitch	·660	150	1·13	622	6·00	544	·01410
„ red	·657	150	·76	511	5·83	447	·00940
Poon	·579	150	·82	846	5·92	740	·01023
Teak	·745	300	1·15	938	4·32	821	·00716

TABLE IX.—*Experiments on the Strength of Beams supported at both ends.*

Kind of Wood.	Specific gravity.	Length in feet L.	Breadth in inches B.	Depth in inches. D.	Deflexion at the time of fracture in inches.	Weight in middle that broke the piece in lbs. W.	Values of the constant c, $= \frac{W.L.}{B.D^2}$	Authorities.
Oak, English, young tree	·863	2	1	1	1·87	482	964	Tredgold.
Oak, old ship timber	·872	2·5	1	1	1·5	264	660	Idem.
„ from old tree ...	·625	2	1	1	1·38	218	436	Idem.
„ „ ...	·791	4	3	3	...	3,692	547	Fincham.
„ medium quality	·748	2·5	1	1	...	284	710	Ebbels.
„ green	·763	2·5	1	1	...	219	547	Idem.
„ from Riga ...	·688	2	1	1	1·25	357	714	Tredgold.
„ green	1·063	11·75	8·5	8·5	3·2	25,812	595	Buffon.
„ Canadian ...	·802	4	3	3	...	3,863	572	Fincham.
„ Adriatic ...	·679	4	3	3	...	4,031	597	Idem.
„ Istrian	1·221	4	3	3	...	4,192	621	Idem.
„ Italian	1·077	4	3	3	...	4,345	644	Idem.
„ Styrian ...	1·008	4	3	3	...	3,792	561	Idem.
„ Dantzic ...	·704	4	3	3	...	4,450	659	Idem.
„ African... ...	1·021	4	3	3	...	6,708	993	Idem.
Teak, Malabar ...	·724	4	3	3	...	4,897	725	Idem.
„ Moulmein ...	·909	4	3	3	...	3,841	569	Idem.
„ Isle of France	·709	4	3	3	...	5,079	752	Idem.
Beech, medium quality	·690	2·5	1	1	...	271	677	Ebbels.
Alder	·555	2·5	1	1	...	212	530	Idem.
Plane-tree	·648	2·5	1	1	...	243	607	Idem.
Sycamore	·590	2·5	1	1	...	214	535	Idem.
Chestnut, green ...	·875	2·5	1	1	...	180	450	Idem.
Ash, from young tree	·811	2·5	1	1	2·5	324	810	Tredgold.
„ medium quality	·690	2·5	1	1	...	254	656	Ebbels.

* Barlow's *Strength of Materials.*

TABLE IX.—*continued.*

Kind of Wood.	Specific gravity.	Length in feet L.	Breadth in inches B.	Depth in inches D.	Deflexion at the time of fracture in inches.	Weight in middle that broke the piece in lbs. W.	Values of the constant c, $= \frac{W.L.}{B.D^2}$.	Authorities.
Ash	·753	2·5	1	1	2·38	314	785	Tredgold.
Elm, common ...	·544	2·5	1	1	...	216	540	Ebbels.
,, wych, green ...	·763	2·5	1	1	...	192	480	Idem.
Acacia, green ...	·820	2·5	1	1	...	249	622	Idem.
Mahogany, Spanish, seasoned ...	·853	2·5	1	1	...	170	425	Tredgold.
Ditto, Honduras, seasoned ...	·560	2·5	1	1	...	255	637	Idem.
Ditto	·636	4	3	3	...	3,370	500	Fincham.
Ditto, New South Wales ...	1·382	4	3	3	...	4,119	611	Idem.
Walnut, green ...	·920	2·5	1	1	...	195	487	Ebbels.
Poplar, Lombardy ...	·374	2·5	1	1	...	131	327	Idem.
,, abele ...	·511	2·5	1	1	1·5	228	570	Tredgold.
Willow	·405	2·5	1	1	3	146	365	Idem.
Birch	·720	2·5	1	1	...	207	517	Ebbels.
Cedar of Libanus, dry	·486	2·5	1	1	2·75	165	412	Tredgold.
,, Bermuda ...	·932	4	3	3	...	4,119	610	Fincham.
,, Cuba ...	·524	4	3	3	...	3,727	552	Idem.
,, New South Wales ...	·555	4	3	3	...	3,179	471	Idem.
,, Tasmania ...	·616	4	3	3	...	2,050	304	Idem.
Fir, Norway	·513	4	3	3	...	3,042	451	Idem.
,, Riga	·576	4	3	3	...	3,982	593	Idem.
,, Dantzic	·708	4	3	3	...	4,149	615	Idem.
,, Adriatic... ...	·475	4	3	3	...	2,668	395	Idem.
,, Athol	·398	4	3	3	...	1,946	298	Idem.
,, Riga	·480	2·5	1	1	1·3	212	530	Tredgold.
,, Memel	·553	2·5	1	1	1·15	218	545	Idem.
,, Norway, from Long Sound	·639	2	1	1	1·125	396	792	Idem.
,, Scotch, English growth	·529	2·5	1	1	1·75	233	582	Idem.
,, ,,	·460	2·5	1	1	...	157	392	Ebbels.
,, Christiana, white deal ...	·512	2	1	1	·937	343	686	Tredgold.
,, American, white spruce	·465	2	1	1	1·312	285	570	Idem.
,, spruce, British growth	·555	2·5	1	1	...	186	465	Ebbels.
Pine, American, Weymouth ...	·460	2	1	1	1·125	329	658	Tredgold.
Pine, red	·512	4	3	3	...	3,259	483	Fincham.
,, yellow... ...	·437	4	3	3	...	2,845	421	Idem.
,, pitch	·682	4	3	3	...	3,338	461	Idem.
Larch, Italian ...	·645	4	3	3	...	4,484	664	Idem.
,, Polish ...	·668	4	3	3	...	4,054	601	Idem.
,, Scotch ...	·561	4	3	3	...	3,108	461	Idem.
,, choice specimen	·640	2·5	1	1	3	253	632	Tredgold.
,, medium quality	·622	2·5	1	1	...	223	557	Idem.
,, very young wood	·396	2·5	1	1	1·75	129	322	Idem.
Elm, English ...	·657	4	3	3	...	3,267	484	Fincham.
,, Canadian ...	·834	4	3	3	...	6,525	967	Idem.
Cowrie	·614	4	3	3	...	3,732	553	Idem.

TABLE X.—*Transverse Strength of Beams of American Timber.**

Kind of Wood.	Specific gravity.	Values of constant *c*.	Values of modulus of elasticity E.	Values of constant *a*.
Ash, white, unseasoned ...	·781	646	1,928,930	·0089
„ „ „	·698	653	1,764,766	·0097
„ „ partly seasoned ...	·642	680	1,440,000	·0120
Beech, white, unseasoned ...	·718	453	1,423,060	·0122
„ red, „ ...	·821	530	1,555,200	·0111
„ „ „ ...	·785	579	1,555,200	·0111
„ seasoned	·710	650	1,623,273	·0107
Birch, black, unseasoned ...	·781	462	1,105,920	·0159
„ yellow „ ...	·756	445	1,152,000	·0150
„ dry	·679	842	2,073,600	·0083
Cedar, white (*arbor vitæ*) ...	·355	255	552,960	·0313
Elm (rock), unseasoned ...	·746	672	1,105,920	·0159
„ „ seasoned	·749	874	1,809,320	·0095
Hickory, white...	·836	735	1,152,000	·0150
Oak, white, unseasoned ...	·918	515	1,229,900	·0140
„ „ „	1·034	447	1,120,870	·0154
„ „ (heart) unseasoned	·951	500	1,382,400	·0125
„ „ „ „ ...	·794	574	1,382,400	·0125
„ „ seasoned	·775	702	1,536,000	·0112
„ black, unseasoned ...	·964	555	1,234,300	·0140
Pine, red, „	·506	420	1,102,000	·0157
Spruce, black, „	·670	370	1,254,000	·0138
„ „ „	·875	321	977,554	·0177

TABLE XI.—*Experiments on the Stiffness of Beams supported at one end.*

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of constant quantity *b*.	Authorities.
Dantzic oak	·854	4	2	2	2·5	112	·232	Beaufoy.
English oak	·922	4	2	2	1·176	112	·105	Idem.
Ditto, another specimen	...	4	2	2	1·5	112	·1335	Idem.
Riga fir	·537	4	2	2	1·34	112	·12	Idem.
Pitch pine	...	4	2	2	1·12	112	·099	Idem.
Beech	...	3	2	2	3·375	221	·313	Barlow.
Riga fir	·605	2	3	3	1·02	1,120	·37	Fincham.
Red pine	·544	2	3	3	1·42	1,120	·51	Idem.
American spruce ...	·504	2	3	3	1·32	1,120	·48	Idem.
Adriatic fir	·467	2	3	3	1·00	1,120	·36	Idem.
Cowrie	·626	2	3	3	·75	1,120	·27	Idem.
Poona	·654	2	3	3	·62	1,120	·224	Idem.

* From experiments by Lieut. Dennison, R.E., *Trans. Inst. Civil Engineers*, vol. ii.

TABLE XII.—*Experiments on the Strength of Beams supported at one end.*

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflexion at the time of fracture in inches.	Weight that broke the piece in lbs.	Values of constant *d*.	Experimentalist.
English oak	·922	4	2	2	...	266	133	Beaufoy.
Ditto	...	4	2	2	...	210	105	Idem.
Dantzic oak	·854	4	2	2	...	196	98	Idem.
Beech	·700	3	2	2	11	401	150	Barlow.
Ditto	·740	2	1	2	5	352	176	Idem.
Ash	·658	3	2	2	$11\frac{1}{2}$	436	163	Idem.
Ditto	·730	2	1	2	6	321	160	Idem.
Ditto, green	·858	5	2	2	16	239	149	Peake and Barralier.
Teak, old, dry	·606	5	2	2	$12\frac{1}{2}$	257	161	Idem.
Riga fir	·337	4	2	2	...	210	105	Beaufoy.
Virginian yellow pine...	·522	5	2	2	$11\frac{3}{4}$	147	92	Peake and Barralier.
Canadian white pine ...	·618	5	2	2	$18\frac{3}{4}$	122	76	Idem.
Pitch pine	...	4	2	2	...	270	135	Beaufoy.
Larch, dry	·526	5	2	2	$16\frac{1}{4}$	162	101	Peake and Barralier.
Riga (yellow pine) ...	·605	2	3	3	...	1,848	137	Fincham.
Red pine	·544	2	3	3	...	1,630	120	Idem.
Cowrie	·626	2	3	3	...	1,960	145	Idem.
Poona	·654	2	3	3	...	2,086	154	Idem.

TABLE XIII.—*Crushing Strength of Short Pieces of Wood, in lbs. per square inch of section.*

Kind of Wood.	Experiments by Eaton Hodgkinson.*		Experiments by T. Laslett.†	
	Unseasoned.	Seasoned.	Specific gravity.	
	lbs.	lbs.		lbs.
Alder	6,831	6,960	...	...
Ash, English	8,683	9,363	·750	6,965
„ Canadian	...	...	·588	5,495
Baywood	7,518	7,518	...	...
Beech	7,733	9,363	...	...
Birch, American	...	11,663	...	...
„ English	3,297	6,402	...	...
Cedar	5,674	5,863	·469	4,480
Crab	6,499	7,148	...	...
Deal, red	5,748	6,586	...	...
„ white	6,781	7,293	...	...
Elder	7,451	9,973	...	...
Elm, English	...	10,331	·642	5,786
„ Canadian	...	...	·748	8,586
Fir, Dantzic	...	...	·756	6,948
„ Riga	...	...	·570	5,248
„ Spruce (England) ...	6,499	6,819	...	...
„ „ (Canada) ...	...	...	·484	4,852
Greenheart	...	...	1·141	14,411
Hornbeam	4,533	7,289	·819	8,313
Larch (fallen two months) ...	3,201	5,568	...	...
„ Russian	...	...	·649	5,815
Mahogany, Spanish	8,198	8,198	·765	6,415
„ Honduras ...	...	...	·659	6,395
Oak, American white ...	...	...	·969	6,451
„ „ live	...	...	·742	5,991
„ African	...	...	·993	10,002
„ Dantzic	...	7,731	·838	7,558
„ English	6,484	10,058	...	...
„ „ unseasoned ...	...	...	·966	4,905
„ „ seasoned ...	...	...	·740	7,475
„ French	...	...	·977	7,945
„ Quebec	4,231	5,982	...	...
„ Sardinian	...	...	·991	5,833
„ Tuscan	...	...	1·041	5,459
Pines, pitch	6,790	6,790	·659	6,462
„ red	5,395	7,518	·353	5,600
„ yellow	5,375	5,445	·471	4,234
Plum, wet	3,654	...	...	...
„ dry	8,241	10,493	...	...
Poplar...	3,107	5,124	...	...
Sycamore	7,082	...	...	...
Teak	...	12,101	·777	5,733
Walnut	6,063	7,227	...	...
Willow	2,898	6,128	...	...

* *Philosophical Transactions*, 1840.

† *Timber and Timber Trees*, 1875.

TABLE XIV.—*Lamandé's Experiments on the Resistance of Oak Beams to Forces pressing in the Directions of their Length.**

Kind of Wood.	Length in feet.	Breadth in inches.	Thickness in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of *e*.	Duration of the experiments in hours.	Weight that broke the piece in lbs.
Oak, seasoned	2·125	2·126	2·126	·0787	7,856	·00060	4	15,631
				·03937	13,525	·00033	6	21,296
				·1181	14,119	·00032	18	19,993
				·03937	11,750	·00042	8	21,060
				·0787	6,298		21	11,844
,, ,,	4·25	2·126	2·126	·1574	6,298	·00020	27	12,225
				·1574	6,298		...	13,565
				·1574	6,298		6	12,458
				·1574	3,277	·00015	6	7,244
,, ,,	6·375	2·126	2·126	·1574	2,860	·00018	...	7,484
				·2361	2,750	·00019	5	8,492
				·1574	2,750		...	7,878
,, ,,	1·25	3·18	3·18	·0787	34,559	·00070	27	50,958
				·03937	45,168	·00050	24	50,958
				·1574	20,317	·00030	29	43,639
,, ,,	4·25	3·18	3·18	·1574	18,637	·00031	5	36,865
				·19685	20,578	·00030	9	36,205
				·27559	21,819	·00026	17	28,182
				·1574	9,121	·00028	7	26,939
				·19685	9,713	·00027	19	28,987
,, ,,	6·375	3·18	3·18	·0787	11,000	·00023	4	23,929
				·2361	10,142	·00025	18	33,048
				·1574	12,746	·00020	6	36,902
				·0787	61,883	·00118	11	95,262
				·03937	56,691	·00129	8	66,112
,, ,,	2·125	4·25	4·25	·03937	56,693		23	105,826
				·0787	67,467	·00107	28	94,476
				·03937	57,780	·00125	30	88,442
				·03937	63,066	·00027	8	100,755
,, ,,	4·25	4·25	4·25	·0787	29,695	·00060	5	85,998
				·0787	50,525	·00035	19	73,238
				·03937	45,201	·00040	19	96,368
				·1574	21,586	·00038	7	64,090
,, ,,	6·375	4·25	4·25	·2361	17,331	·00047	5	59,373
				·1574	18,517	·00044	22	54,062
				·1361	27,599	·00030	22	65,608
					Mean	·00043		

* Gauthey, *Construction des Ponts.*

TABLE XV.—*Girard's Experiments on the Resistance of Oak when compressed in the Direction of its Length.*

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Thickness in inches.	Deflexion in inches.	Weight producing the deflexion in lbs.	Values of *e*.	Duration of the experiments in hours.	Weight that broke the piece in lbs, or remarks.
Oak ...	1·038	8·52	6·22	5·06	0·268	38,105	0·00029	0·83	Recovered its first form.
,, ...	1·010	8·52	6·22	4·00	0·09	26,381	0·00020	0·83	Retained a slight flexure.
,, ...	1·000	8·52	5·24	3·9	0·445	26,384	0·00016	6·66	Idem.
,, ...	·923	8·52	5·15	4·17	0·665	26,392	0·00019	6·66	50,448
,, ...	·973	7·46	6·22	5·06	not sensible.	38,098	0·00038	0·83	
					0·157	50,454	0·00028	2·08	Recovered its first form.
,, ...	·972	7·46	6·13	4·09	0·244	38,104	0·00019	12·08	72,865
,, ...	·925	7·46	6·22	4·00	0·267	38,106	0·00018	12·08	62,977
,, ...	1·038	7·46	4·97	4·00	0·312	26,397	0·00021	10·00	Retained a slight flexure.
,, ...	1·102	6·39	6·13	5·24	0·177	38,107	0·00057	7·08	Idem.
,, ...	·987	6·39	6·22	4·00	0·177	38,106	0·00025	2·08	Recovered its first form.
,, ...	1·032	6·39	5·24	4·17	0·22	38,048	0·00024	10·00	Idem.
,, ...	·920	7·46	6·22	4·25	0·114	26,396	0·00032	10·00	Idem.
,, ...	1·038	8·52	6·22	5·06	0·177	26,392	0·00042	10·00	
,, ...	·944	8·52	7·37	6·22	0·09	26,394	0·00090	10·00	Recovered its first form.
,, ...	·842	8·52	7·46	6·22	0·09	26,396	0·00093	10·00	
						Mean	0·00036		

TABLE XVI.—*Constant Numbers to be used in calculating the Dimensions of Columns, Posts, and other Beams, pressed in the Direction of their Length.*

Kind of Wood.	Modulus of elasticity in lbs. E.	Value of *e*, the constant number in the rules.
English oak	1,714,500	0·00150
Beech	1,316,000	0·00195
Alder	1,086,750	0·00230
Chesnut, green	924,750	0·00267
Ash	1,525,500	0·00168
Elm	1,343,000	0·00184
Acacia	1,687,500	0·00152
Mahogany, Spanish	1,255,500	0·00205
,, Honduras ...	1,593,000	0·00161
Teak	2,167,074	0·00118
Cedar, Lebanon	486,000	0·00530
Riga fir	1,687,500	0·00152
Memel fir	1,957,750	0·00133
Norway spruce fir	1,804,000	0·00142
Weymouth pine	1,633,500	0·00157
Larch	1,363,500	0·00190

TABLE XVII.—*Hodgkinson's Experiments on Square Pillars.**

DANTZIC OAK.

Pillar.	Length.	Breadth.	Deflexion.	Load producing deflexion.	Breaking-weight.
	inches.	inches.	inches.	lbs.	lbs.
Both ends rounded	60·5	1·75	·09	2,137	3,645
	,,	,,	·13	2,141	2,749
	,,	,,	·11	3,197	...
	,,	,,	·20	5,437	...
One end rounded and other end flat.	,,	,,	·48	7,229	7,229
	,,	,,	·11	2,270	...
	,,	,,	·19	3,614	...
	,,	,,	·32	4,541	4,989
	,,	,,	·14	9,499	10,171
	,,	,,	·09	6,139	8,323
	,,	,,	·04	6,811	...
	,,	,,	·14	8,827	8,827
Both ends flat ...	29·75	1·75	...	...	13,083
	30·25	1·75	...	...	14,305
	48·0	1·75	...	...	9,229
	46·1	1·02	...	...	1,754
	,,	1·5	...	...	7,888

RED DEAL.

Pillars 58 inches long; area of Section 4 square inches.

Ratio of sides.	Deflexion.	Load.	Breaking-weight.
	inches.	lbs.	lbs.
1 : 1	·10	6,505	...
	·17	11,209	12,385
	·12	6,505	...
	·32	11,209	11,601
1 : 2	·13	4,153	...
	·25	6,505	7,681
1 : 3	·42	4,153	4,349

* *Philosophical Transactions*, 1840.

TABLE XVIII.—*Experiments on Resistance to a gradually increasing Thrust of logs of Fir, by D. Kirkaldy.**

Kind of Wood.	Length in feet.	Scantling in inches.	Depression. inches.	Set. inches.	Horizontal deflexion.	Vertical deflexion.	Weight producing depression in lbs.	Ultimate stress in lbs. per square inch.
White Riga	20	13×13	·194	·010	·34	0	100,000	...
	,,	,,	·273	·014	·41	0	150,000	...
	,,	,,	·358	·016	·47	0	200,000	...
	,,	,,	·434	,,	·53	0	250,000	...
	,,	,,	·523	·022	·64	0	300,000	...
	ultimate stress		...	...	... ...	... ...	331,260	1,960
Red Dantzic	20	13·5×13	·203	...	·08	·10	100,000	...
	,,	,,	·276	...	...	...	150,000	...
	,,	,,	·346	·020	·19	·22	200,000	...
	,,	,,	·414	...	·25	·29	250,000	...
	,,	,,	·548	·033	·47	·55	300,000	...
	ultimate stress		...	...	... ...	... ...	309,120	1,742

The former of these gave way at knots 2 feet 9 inches off the centre; the latter at knots 9 inches from the centre.

TABLE XIX.—*Scantlings for Story-Posts, to carry two Stories.*

Height in feet.	4 feet apart.	5 feet apart.	6 feet apart.	7 feet apart.	8 feet apart.	Height in feet.
	width. thickness.	width. thickness.	width. thickness.	width. thickness.	width. thickness.	
	inches.	inches.	inches.	inches.	inches.	
6	$7\frac{1}{2}$ × $4\frac{1}{2}$	$7\frac{3}{4}$ × $4\frac{3}{4}$	$8\frac{1}{4}$ × 5	$8\frac{3}{4}$ × $5\frac{1}{4}$	$9\frac{1}{4}$ × $5\frac{1}{2}$	6
7	$7\frac{3}{4}$ $4\frac{3}{4}$	$8\frac{3}{4}$ $5\frac{1}{4}$	$9\frac{1}{4}$ $5\frac{1}{2}$	$9\frac{1}{2}$ $5\frac{3}{4}$	$9\frac{1}{2}$ $5\frac{3}{4}$	7
8	$8\frac{3}{4}$ $5\frac{1}{4}$	$9\frac{1}{4}$ $5\frac{1}{2}$	$9\frac{1}{2}$ $5\frac{3}{4}$	10 6	$10\frac{1}{2}$ $6\frac{1}{4}$	8
9	$9\frac{1}{4}$ $5\frac{1}{2}$	$9\frac{1}{2}$ $5\frac{3}{4}$	$10\frac{1}{2}$ $6\frac{1}{4}$	$10\frac{3}{4}$ $6\frac{1}{2}$	$10\frac{3}{4}$ $6\frac{3}{4}$	9
10	$9\frac{1}{2}$ $5\frac{3}{4}$	$10\frac{1}{2}$ $6\frac{1}{4}$	$10\frac{3}{4}$ $6\frac{1}{2}$	$11\frac{1}{4}$ $6\frac{3}{4}$	$11\frac{3}{4}$ 7	10
11	$10\frac{1}{2}$ $6\frac{1}{4}$	$10\frac{3}{4}$ $6\frac{1}{2}$	$11\frac{1}{2}$ $6\frac{3}{4}$	$11\frac{3}{4}$ 7	12 $7\frac{1}{4}$	11
12	$10\frac{3}{4}$ $6\frac{1}{2}$	$11\frac{1}{4}$ $6\frac{3}{4}$	$11\frac{3}{4}$ 7	$12\frac{1}{2}$ $7\frac{1}{2}$	$12\frac{3}{4}$ $7\frac{3}{4}$	12
13	$11\frac{1}{4}$ $6\frac{3}{4}$	$11\frac{3}{4}$ 7	$12\frac{1}{2}$ $7\frac{1}{2}$	$12\frac{3}{4}$ $7\frac{3}{4}$	$13\frac{1}{4}$ 8	13
14	$11\frac{3}{4}$ 7	12 $7\frac{1}{4}$	$12\frac{3}{4}$ $7\frac{3}{4}$	$13\frac{1}{4}$ 8	$13\frac{3}{4}$ $8\frac{1}{4}$	14
15	12 $7\frac{1}{4}$	$12\frac{1}{2}$ $7\frac{1}{2}$	$13\frac{1}{4}$ 8	$13\frac{3}{4}$ $8\frac{1}{4}$	$14\frac{1}{4}$ $8\frac{1}{2}$	15
16	$12\frac{1}{2}$ $7\frac{1}{2}$	$12\frac{3}{4}$ $7\frac{3}{4}$	$43\frac{3}{4}$ $8\frac{1}{4}$	$14\frac{1}{4}$ $8\frac{1}{2}$	$14\frac{1}{2}$ $8\frac{3}{4}$	16

The stories supported are supposed to be constructed with brick, according to the regulations detailed in the Building Act.

* From the *Transactions of the Royal Institute of British Architects*, 1872.

TABLE XX.—*Scantlings for Story-Posts, to carry three Stories.*

Height in feet.	4 feet apart.	5 feet apart.	6 feet apart.	7 feet apart.	8 feet apart.	Height in feet.
	width. thickness.	width. thickness.	width. thickness.	width. thickness.	width. thickness.	
	inches.	inches.	inches.	inches.	inches.	
8	$9\frac{1}{2} \times 5\frac{3}{4}$	10×6	$10\frac{3}{4} \times 6\frac{1}{2}$	$11\frac{1}{4} \times 6\frac{3}{4}$	$11\frac{3}{4} \times 7$	8
9	$10 \quad 6$	$10\frac{3}{4} \quad 6\frac{1}{2}$	$11\frac{1}{4} \quad 6\frac{3}{4}$	$11\frac{3}{4} \quad 7$	$12 \quad 7\frac{1}{4}$	9
10	$10\frac{3}{4} \quad 6\frac{1}{2}$	$11\frac{1}{4} \quad 6\frac{3}{4}$	$12 \quad 7$	$12\frac{1}{4} \quad 7\frac{1}{4}$	$12\frac{1}{2} \quad 7\frac{3}{4}$	10
11	$11\frac{1}{4} \quad 6\frac{3}{4}$	$11\frac{3}{4} \quad 7$	$12\frac{1}{2} \quad 7\frac{1}{4}$	$12\frac{3}{4} \quad 7\frac{3}{4}$	$13\frac{1}{4} \quad 8$	11
12	$11\frac{3}{4} \quad 7$	$12\frac{1}{2} \quad 7\frac{1}{4}$	$13 \quad 7\frac{3}{4}$	$13\frac{1}{4} \quad 8$	$14 \quad 8\frac{1}{4}$	12
13	$12 \quad 7\frac{1}{4}$	$12\frac{3}{4} \quad 7\frac{3}{4}$	$13\frac{3}{4} \quad 8\frac{1}{4}$	$14 \quad 8\frac{1}{2}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	13
14	$12\frac{3}{4} \quad 7\frac{3}{4}$	$13\frac{1}{4} \quad 8$	$14\frac{1}{4} \quad 8\frac{1}{2}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	$15 \quad 9$	14
15	$13\frac{1}{4} \quad 8$	$14\frac{1}{4} \quad 8\frac{1}{2}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	$15 \quad 9$	$15\frac{3}{4} \quad 9\frac{1}{4}$	15
16	$13\frac{3}{4} \quad 8\frac{1}{4}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	$15 \quad 9$	$15\frac{1}{2} \quad 9\frac{1}{4}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	16

TABLE XXI.—*Scantlings for Story-Posts, to carry four Stories.*

Height in feet.	4 feet apart.	5 feet apart.	6 feet apart.	7 feet apart.	8 feet apart.	Height in feet.
	width. thickness.	width. thickness.	width. thickness.	width. thickness.	width. thickness.	
	inches.	inches.	inches.	inches.	inches.	
8	$10\frac{1}{4} \times 6\frac{1}{4}$	$10\frac{3}{4} \times 6\frac{1}{2}$	$11\frac{1}{2} \times 6\frac{3}{4}$	12×7	$12\frac{1}{4} \times 7\frac{1}{4}$	8
9	$10\frac{3}{4} \quad 6\frac{1}{2}$	$11\frac{3}{4} \quad 7$	$12 \quad 7\frac{1}{4}$	$12\frac{1}{2} \quad 7\frac{1}{2}$	$12\frac{3}{4} \quad 7\frac{3}{4}$	9
10	$11\frac{3}{4} \quad 6\frac{3}{4}$	$12 \quad 7\frac{1}{4}$	$12\frac{1}{2} \quad 7\frac{3}{4}$	$13\frac{1}{4} \quad 8$	$13\frac{3}{4} \quad 8\frac{1}{4}$	10
11	$12 \quad 7\frac{1}{4}$	$12\frac{1}{2} \quad 7\frac{3}{4}$	$13\frac{1}{4} \quad 8$	$14 \quad 8$	$14\frac{1}{4} \quad 8\frac{1}{2}$	11
12	$12\frac{1}{2} \quad 7\frac{1}{2}$	$13\frac{1}{4} \quad 8$	$14\frac{1}{4} \quad 8\frac{1}{2}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	12
13	$13 \quad 7\frac{3}{4}$	$14 \quad 8\frac{1}{4}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	$15 \quad 9$	$15\frac{1}{2} \quad 9\frac{1}{4}$	13
14	$13\frac{1}{2} \quad 8\frac{1}{4}$	$14\frac{1}{4} \quad 8\frac{3}{4}$	$15 \quad 9$	$16 \quad 9\frac{1}{2}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	14
15	$14\frac{1}{2} \quad 8\frac{3}{4}$	$15 \quad 9$	$16 \quad 9\frac{1}{2}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	$16\frac{3}{4} \quad 10$	15
16	$15 \quad 9$	$15\frac{1}{2} \quad 9\frac{1}{2}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	$16\frac{3}{4} \quad 10$	$17\frac{1}{2} \quad 10\frac{1}{2}$	16

TABLE XXII.—*Scantlings for Story-Posts, to carry five Stories.*

Height in feet.	4 feet apart.	5 feet apart.	6 feet apart.	7 feet apart.	8 feet apart.	Height in feet.
	width. thickness.	width. thickness.	width. thickness.	width. thickness.	width. thickness.	
	inches.	inches.	inches.	inches.	inches.	
8	$11\frac{1}{4} \times 6\frac{3}{4}$	$11\frac{3}{4} \times 7$	$12\frac{1}{4} \times 7\frac{1}{4}$	$12\frac{3}{4} \times 7\frac{3}{4}$	$13\frac{1}{4} \times 8$	8
9	$11\frac{3}{4} \quad 7$	$12\frac{1}{2} \quad 7\frac{1}{2}$	$12\frac{3}{4} \quad 7\frac{3}{4}$	$13\frac{1}{4} \quad 8$	$14\frac{1}{4} \quad 8\frac{1}{2}$	9
10	$12\frac{1}{2} \quad 7\frac{1}{2}$	$13\frac{1}{4} \quad 8$	$13\frac{3}{4} \quad 8\frac{1}{4}$	$14\frac{1}{4} \quad 8\frac{1}{2}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	10
11	$12\frac{3}{4} \quad 7\frac{3}{4}$	$13\frac{3}{4} \quad 8\frac{1}{4}$	$14\frac{1}{4} \quad 8\frac{1}{2}$	$15 \quad 9$	$15\frac{1}{2} \quad 9\frac{1}{4}$	11
12	$13\frac{1}{4} \quad 8\frac{1}{4}$	$14\frac{1}{4} \quad 8\frac{1}{2}$	$14\frac{1}{2} \quad 8\frac{3}{4}$	$16 \quad 9\frac{1}{2}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	12
13	$14\frac{1}{4} \quad 8\frac{1}{2}$	$15 \quad 9$	$15\frac{1}{2} \quad 9\frac{1}{4}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	$16\frac{3}{4} \quad 10$	13
14	$14\frac{1}{2} \quad 8\frac{3}{4}$	$15\frac{1}{2} \quad 9\frac{1}{4}$	$16\frac{1}{4} \quad 9\frac{3}{4}$	$16\frac{3}{4} \quad 10$	$17\frac{1}{2} \quad 10\frac{1}{2}$	14
15	$15 \quad 9$	$16 \quad 9\frac{1}{2}$	$16\frac{3}{4} \quad 10$	$17\frac{1}{2} \quad 10\frac{1}{2}$	$17\frac{3}{4} \quad 10\frac{3}{4}$	15
16	$16 \quad 9\frac{1}{2}$	$16\frac{3}{4} \quad 10$	$17\frac{1}{2} \quad 10\frac{1}{2}$	$17\frac{3}{4} \quad 10\frac{3}{4}$	$18\frac{1}{4} \quad 11$	16

In these tables the stories supported are supposed to be constructed with brick, according to the regulations contained in the Act of Parliament called the Building Act.

SECTION III.

ON THE CONSTRUCTION OF FLOORS.

135.—THE timbers which support the flooring boards and ceiling of a room are called, in carpentry, the *naked flooring*. There are different kinds of naked flooring, but they may be all comprised under the three following denominations, viz.: single-joisted floors, double floors, and framed floors.

First, single-joisted floors. A single-joisted floor consists of only one series of joists. *Plate* IV., *fig.* 38, shows a section across the timbers of a single-joisted floor.

Sometimes every third or fourth joist is made deeper, and the ceiling joists fixed to the deep joists, and crossing them at right angles. This is an improvement in a situation where there is not space for a double floor. *Fig.* 39 shows a section of a floor of this kind. It increases the depth of the floor very little, and will not allow sounds to pass so freely as a single-joisted floor, and the ceilings will stand better. The ceiling joists, *a*, *a*, are notched to the deep joists *b*, *b*, *b*, and nailed.

Secondly, double floors. A double floor consists of three tiers of joists: that is, binding joists, bridging joists, and ceiling joists; the binding joists are the chief support of the floor, and the bridging joists are notched upon the upper side of them; the ceiling joists are either notched to the under side, or framed between with chased mortises; the best method is to notch them. *Fig.* 40 shows a section of a double floor across the binding joists *b*, *b*, *b*. The bridging joists *d*, *d*, are notched over, and the ceiling joists *a*, *a*, are notched under the binding joists.

Thirdly, framed floors differ from double floors only in having the binding joists framed into large pieces of timber, called girders. *Fig.* 41 shows a section across the girders of a framed floor; where *b*, *b*, *b*, are the binding joists.

Single joisting makes a much stronger floor, with the same quantity of timber, than a double or framed floor, and may be constructed with equal ease to the same extent of bearing; but the ceilings are more subject to cracks and irregularities; consequently single-joisted floors of long bearings can be used only in inferior buildings.

136.—When it is desirable to exhibit a perfectly plane ceiling of plaster, a double floor is used; and when this is required and the bearing is long, a framed floor becomes most convenient. The following experiment was made on the comparative strength of framed and single-joisted floors by Professor Robison.

Two models were made 18 inches square; one consisted of single joists, the other framed with girders, binding joists, bridging and ceiling joists; the single joists of the one contained the same quantity of timber with the girders alone of the other. They were placed in a

wooden trunk 18 inches square within, with a strong projection on the inside for the floors to rest on; and small shot was gradually poured over.

The single-joisted floor broke down with 487 lbs., the framed floor with 327 lbs. The difference would not be quite so much on a large scale, because the girders would not be so much weakened by mortises. This is not the only case where apparent strength has turned out to be real weakness, and shows how necessary it is to distinguish those parts which really support a load from those which only appear to do so.

ON SINGLE-JOISTED FLOORS.

137.—In order to make a stiff floor with a small quantity of timber, the joists should be thin and deep; but a certain degree of thickness is necessary, for the purpose of nailing the boards, and 2 inches is perhaps quite as thin as the joists ought to be made, though sometimes they are made thinner.

To find the depth of a joist, the length of bearing and breadth being given, for a single-joisted floor, when the distance apart from middle to middle is 12 inches.

As the joists of a floor are covered with boarding we may consider that the load is pretty uniformly distributed thereby over their entire length, and use the formula obtained for stiffness in Art. 97, namely:

$$B \cdot D^3 = \cdot 625\ a \cdot w \cdot L^3,$$

where w is the greatest load (including the weight of the timbers themselves) that a joist will be required to support upon every foot of its length; a the constant given in Tables II., V., VI., VII., VIII., and X.; L the length in feet, B and D the breadth and depth in inches. Taking $a = \cdot 01$ for fir, and $w = 120$ lbs., we have

$$D^3 = \frac{3\ L^3}{4\ B}.$$

RULE. Divide three times the cube of the length in feet by four times the breadth in inches, and the cube root of the quotient will give the depth in inches of a fir joist.

Example. Required the proper depth for a fir joist, the bearing being 12 feet and the breadth 2 inches?

Here, $\frac{3 \times 1728}{4 \times 2} = 648$, and the cube root of 648 is 8·7, the depth required; or $8\frac{3}{4}$ inches is near enough in practice.

The scantlings of joists in Table XXV. are calculated by means of the above rule.

On account of flues, fire-places, and other causes, it often happens that the joists cannot have a bearing on the wall. In such cases a piece of timber, called a *trimmer*, is framed between two of the nearest joists that have a bearing on the wall. Into this trimmer the ends of the joists to be supported are mortised. This operation is called *trimming*. The scantlings of trimmers may be found by the same rule as those for binding joists, Art. 147; the length of the joists framed into the trimmer being equivalent to the distance apart in binding joists.

The two joists which support the trimmer are called *trimming joists*, and they should be stronger than the common joists. In general it will be sufficient to add one-eighth of an inch to the thickness of a trimming joist for each joist supported by the trimmer. Thus, if the thickness of the common joists be 2 inches, and a trimmer supports four joists, then add four-eighths, or half-an-inch; that is, make the trimming joists each $2\frac{1}{2}$ inches in thickness. In practice, however, it is usual to have the trimmers 1 inch thicker than the joists.

When the bearing exceeds 8 feet, single joisting should be strutted between the joists to prevent them turning or twisting sideways, and also to stiffen the floor; when the bearing exceeds 12 feet, two rows of struts will be necessary, and so on, adding another row of struts for each increase of 4 feet in bearing. These struts should be in a continued line across the floor, and short ends of boards put in moderately tight, and nearly of the depth of the joists, are quite sufficient; indeed, such pieces simply nailed are better than keys mortised into the joists, because they require less labour, and do not weaken the joists with mortises. The well fitting of the struts is an essential part in making a good ceiling. A method called *herring-bone strutting* is now commonly used, which consists of slips of wood placed crosswise between the joists and nailed thereto.

For common purposes single joisting may be used to any extent that timber can be got deep enough for; but where it is desirable to have a perfect ceiling, the bearing should not exceed about 10 feet, on account of the partial strains produced by heavy furniture, such as bedsteads and the like, of which the greater part may rest upon only two or three of the joists, and of course bend these below the rest so as to break the ceiling. Also, where it is desirable to prevent the passage of sound from one floor to another, a fillet of wood is nailed half-way down each side of the joists, on which are laid rough pieces of board to receive a coat of coarse plaster called *pugging*.

The passage of sound may be reduced in a single-joisted floor, by putting strips of list or thin slices of cork along the upper edges of the joists, to nail the boards down upon.

ON FRAMED FLOORS.

Framed floors consist of girders, binding joists, bridging joists, and ceiling joists.

Girders.

138.—The girders are the chief support of a framed floor, being placed across the room from wall to wall; on these the *binders* are framed at distances apart of about 6 feet, the girders being placed at intervals of about 10 feet. The weight of flooring which the girders sustain will depend to some extent on the number of the binders; if the span is about 12 feet there will be but one binder which will be at the centre of the beam, which will have to carry half the weight of the floor, the other half being borne directly by the walls upon which the ends of the *bridging* joists rest; consequently, from Art. 46, if W is the entire load of the floor, the moment of strain at the centre will be

$$M = \frac{W}{2}\left(\frac{L}{4}\right) \qquad \text{(Case I.)}$$

If the girder is more than 12 feet and less than 20 feet in length, it will have two binders resting upon it, and will have to support two-thirds of W, or one-third W at each binder; consequently, by Art. 46,

$$M = \frac{W}{3} \cdot \frac{L}{3} = \frac{4}{9} W \left(\frac{L}{4}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \text{(Case II.)}$$

is the moment of strain at the centre.

If the length of the girder is from 20 to 24 feet, the number of the binders will be three, and the girder will carry three-fourths of the load, one of the points of support being at the centre and the others at one-fourth of its length from the end. The moment of strain at the centre will be

$$M = 2 \frac{W}{4} \cdot \frac{1}{4} \cdot \frac{1}{2} L + \frac{W}{4} \cdot \frac{L}{4} = \frac{W}{2} \left(\frac{L}{4}\right) \quad \ldots \quad \ldots \quad \ldots \quad \text{(Case III.)}$$

When the girder is 30 feet long the binders will rest on it at four points, and the moment of strain at the centre will be

$$M = \frac{3}{25} W \cdot L = \frac{12}{25} W \cdot \left(\frac{L}{4}\right) \quad \ldots \quad \ldots \quad \ldots \quad \text{(Case IV.)}$$

When there are more than four points at which the purlins rest on the girder, the moment of strain at the centre may be taken as that of half W placed at the centre.

139.—In order to find the scantling of a girder which shall have the requisite stiffness to sustain the load in either of the above-mentioned cases, we take the formula of Art. 89, namely:—

$$\frac{B \times D^3}{L^2 \cdot W} = a,$$

and substitute for W therein the values,

$$\frac{W}{2} \text{ (Case I.)}, \frac{4}{9} W \text{ (Case II.)}, \frac{W}{2} \text{ (Case III.)}, \frac{12}{25} W, \text{ (Case IV.)}$$

and by this means we calculate the scantling of a girder of any given length and mode of loading.

Case I. When $\frac{1}{2}$W is supported at the middle of the girder,

$$B = \frac{a \cdot W \cdot L^2}{2 D^3} = \frac{a \cdot w L^3}{2 D^3} = \frac{6 L^3}{D^3}$$

for fir, when $a = \cdot 01$; since $W = w \cdot L$, where w is the load on each foot length of the girder, and is 1,200 lbs. when the girders are 10 feet from centre to centre.

Case II. When $\frac{1}{3}$W is supported at each of two points of the girder,

$$B = \frac{4 a \cdot w \cdot L^3}{9 D^3} = \frac{16 L^3}{3 D^3}.$$

Case III. When $\frac{1}{4}$ W is supported at each of three points on the girder,

$$B = \frac{a \cdot w \cdot L^3}{2\,D^3} = \frac{6\,L^3}{D^3}.$$

Case IV. When $\frac{1}{5}$ W is supported at each of four points on the girder,

$$B = \frac{12\,a \cdot w \cdot L^3}{25\,D^3} = \frac{29\,L^3}{5\,D^3}.$$

When the girder supports binders at five or more points, we can use the formulæ for Case I. or Case III.

The scantlings of the girders in Table XXIII. are calculated from the foregoing formulæ.

In these rules the girders are supposed to be 10 feet apart, and this distance should never be exceeded; but should the distance apart be less or more than 10 feet, the breadth of the girder should be made in proportion to the distance apart.

Girders for long bearings should always be made as deep as they can be got; an inch or two taken from the height of a room is of little consequence, compared with a ceiling disfigured with cracks, besides the inconvenience of not being able to move on the floor without shaking everything in the room.

The above formulæ are for ordinary house floors; but for warehouses the strength should be at least three times as great as that given above, or 360 lbs. on every square foot, or $w = 3{,}600$.

140.—When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn sides outwards; the girders in the section, *fig.* 41, are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. The slips put between the halves, or flitches, should be thick enough to allow the air to circulate freely between them. It is generally imagined that it strengthens a girder to cut it down, reverse it, and bolt it together again; it is in fact weakened by the operation, but the method is recommended here for the reasons above stated.

The timber can only be weakened to the amount of the wood lost by the passage of the saw; and its strength is rendered more uniform by inverting the ends of the two pieces. It rarely happens that the butt and top of a timber have equal strengths. It is therefore reasonable to conclude that the girder is practically strengthened by the process recommended.

Some suppose that girders are cut down merely for the purpose of equalising their stiffness; but admitting a girder to be bent considerably, the difference between the deflexions at any two points equally distant from the middle would not be sensible in girders of the usual form. The person who first practised the method of cutting girders down the middle undoubtedly did it with a view of preserving and not of stiffening them. We find that Vitruvius, the oldest author on architecture whose works are extant, directs a space of two fingers' breadth to be left between the beams for forming the architrave over columns, in order that the air may circulate between and prevent decay. Every one must have observed that decay begins in the first place at the joints, and other parts where the pieces are neither perfectly close, nor yet sufficiently open to allow any dampness to evaporate.

TRUSSED GIRDERS.

141.—When the bearing exceeds about 22 feet it is very difficult to obtain timber large enough for girders, and it is usual in such cases to truss them. The methods in general adopted for that purpose have the appearance of much ingenuity; but in reality they are of very little use. If a girder be trussed with oak, all the strength that can possibly be gained by such a truss consists merely in the difference between the compressibility of oak and fir, which is very small indeed; and unless the truss be extremely well fitted at the abutments, it would be much stronger without trussing. All the apparent stiffness obtained by trussing a beam is procured by forcing the abutments, or, in other words, by cambering the beam. This forcing cripples and injures the natural elasticity of the timber; and the continual spring, from the motion of the floor, upon parts already crippled, it may easily be conceived, will soon so far destroy them as to render the truss a useless burden upon the beam. This is a fact that has been long known to many of our best carpenters, and which has caused them to seek for a remedy in iron trusses; but this method is quite as bad as the former, unless there be an iron tie as an abutment to the truss; for the failure of a truss is occasioned by the enormous compression applied upon a small surface of timber at the abutments. The defects of ordinary trussed girders are very apparent in old ones, as it is not simply strength that is required, but the power of resisting the unceasing concussions of a straining force, capable of producing a permanent derangement in a small surface at every impression.

142.—A method of trussing which was formerly much employed until the introduction of iron girders is shown on Plate V., and is described in Nicholson's *Carpenter's New Guide.*

Figs. A and B show the longitudinal section of the girder formed of two "flitches" of fir, with a truss of oak between them. Good dry, straight-grained English oak should be used, 4 inches by 3 inches, or 6 inches by 4 inches, as the strength may require, and let half into each flitch; the pieces of the core being inserted in the one half, so as to abut firmly at the ends, and the two flitches put together so that the internal braces may abut firmly at the ends of the other flitch, and then bolted together. *Fig.* C is a horizontal section of B. *Fig.* D is a section of the abutment, by cutting across *a b* in A. E and F show the two sides of the iron king-bolt, at *c*, in A, which is made with a wedgeway upon the top, so that it may force out the trusses upon the abutments. The cores of the trusses ought not to be let close into the grooves of the flitches, but should be well secured at the ends and in the middle. To test the value of this kind of trussing Mr. Barlow prepared four models of girders, two being trussed and two plain; the depth being 2 inches and the breadth $1\frac{7}{8}$ inches, the bearing of one model, similar to *fig.* A, being 4 feet 2 inches, and intended to represent a 25-feet girder; and that of the other model, on the plan of *fig.* B, being 5 feet 8 inches, representing a 34-feet girder. The results of the experiments* are given in the table below, and show that in the truss with a king-bolt there was a slight advantage over the plain beam; the latter having broken with 717 lbs., while the former required 953 lbs. to break it. In the case of the queen-truss, the wood of the trussed beam was inferior to that of the plain one, but the truss appeared to add very little to the strength of the beam.

* Barlow on *Strength of Materials* (Crosby Lockwood & Co).

Description.	Length of bearing.	Weight.	Deflection produced by the weight.
	ft. in.	lbs.	
Two truss pieces meeting against a king-bolt in the centre, with plate bolts at the abutments	4 , 2	600	0·87
Piece of the same size without a truss	4 , 2	600	1·00
Three truss pieces, with two queen-bolts, with plate bolts at the abutments	5 , 8	500	2·25
Piece of the same size, without a truss	5 , 8	500	1·55

143.—Another mode of trussing beams which is commonly in use is the reverse of that shown on *Plate* V.; an iron tension rod, taking the place of the oak struts, the beam, as shown in *figs.* A and B, being turned so that *c* is at the bottom. The rod is passed under one or two points at the lowest part of the beam, sloped upwards towards each end, where it is securely fastened with screw nuts and iron plates. Any load placed on the beam which would cause it to bend in the middle immediately brings a tensile force to act upon the iron rod. If W is the load at the centre, and the rod is inclined to the horizontal at an angle θ, then the tensile strain will be $\frac{1}{2}$ W sin. θ, if we neglect the resistance of the beam itself. The depth of the beam must therefore be very considerable as compared with the length, in order to gain much strength by this system of trussing. In some cases the angle θ may be increased by fixing iron stays, projecting below the bottom of the beam, and passing the tension rod over their lower ends.

144.—A different kind of trussed girder is illustrated in *Plate* VI., which shows three examples of trusses. No. 1. Executed over the Thames Plate Glass Works, to carry a pair of transverse principals of a roof of 25 feet span, and also the gutter plate of a roof of 36 feet span, the principals of which run parallel with it.

No. 2 shows a truss executed to carry the principals of a roof of 43 feet span at the late Princess's Theatre, Oxford Street, the situation of the principals being immediately over the queen-post.

The feet of the rafters of this roof, and also of the lean-to, are pitched on a gutter-plate running parallel with the truss, and from the under-tie a floor is framed or suspended by stirrup straps.

Scantlings, No. 1.

Length of bearing	36 feet.
Tie-beam	14 × 7 inches.
Queen-posts	9 × 7 „
Principal truss at foot ...	11 × 6 „
„ „ top... ...	8 × 6 „
Collars...	9 × 6 „
Braces	4½ × 6 „

Scantlings, No. 2.

Length of bearing	35 feet.
Tie-beam	14 × 7 inches.
Queen-posts	9 × 7 „
Principal truss at foot	11 × 7 „
„ „ top	8 × 7 „
Braces	5 × 7 „

No. 3 shows a truss executed to carry a party wall, in which there was an entire stack of

chimneys, for the purpose of enlarging a dining-room at a house in Berkeley Square. Here a cast iron-girder was used in combination with the timber truss.

Timber Scantlings.

Length of bearing	52 feet.
Tie-beam	18 × 12 inches.
Queen-posts	12 × 12 „
Braces	12 × 4 „

Iron Work.

	ft.	in.
Width on Plan	1	2
Sectional depth	3	0
Thickness of casting	0	4
„ flanges	0	4
Wrought-iron stirrups	$5\frac{1}{2} \times 1\frac{1}{2}$	
At the larger end	$5\frac{1}{2} \times 2\frac{1}{2}$	

In casting, the flanges of the girder were widened on the plan, to support the chimney breasts.

145.—Although the usual mode of trussing girders cannot be relied upon, nor indeed any other timber truss that is made within the depth of the beam, yet, by adding to the depth, there are several methods that may be applied with success in extending the bearing of timber girders. The principle of constructing girders of any depth is the same as that of building beams, and when properly conducted is as strong as any truss can be made of the same depth.

The most simple method consists in bolting two pieces together, with keys between, to prevent the parts sliding upon each other; the upper one of hard compact wood, the lower of tough straight-grained. The joints should be at or near the middle of the depth. *Fig.* 42, *Plate* IV., shows a beam put together in this manner. The thickness of all the keys added together should be somewhat greater than one-third more than the whole depth of the girder; and, if they be made of hard wood, the breadth should be about twice the thickness.

Fig. 43 is another girder of the same construction, excepting that it is held together by hoops instead of bolts. The girder being cut so as to be smaller towards the ends, would admit of these hoops being driven on till they would be perfectly tight, and would make a very firm and simple connexion.

In *fig.* 44 the parts are tabled or indented together, instead of being keyed, and a king-bolt is added to tighten the joints; the upper part of the girder being in two pieces. The depth of all the indents added together should not be less than two-thirds of the whole depth of the girder.*

Another method of constructing a girder consists in bending a piece into a curve, and securing it from springing back by bolts or straps. A girder constructed in this manner is shown by *fig.* 45. Mr. Smeaton adopted a similar method of strengthening the beam of a steam-engine,† and the additional stiffness gained by bending beams in this manner is very considerable. The pieces should be well bolted, or strapped, and keys or tables inserted to prevent any sliding of the parts. In this manner a beam might be built of any depth that is necessary in the erection of buildings, and, by breaking the joints, of any length that is likely to be needed in the construction of floors.

* A girder similar to this is described by Mathurin Jousse, in his *Art de la Charpenterie.*

† *Rees's Cyclopædia*, Art. "Steam Engine." Girders constructed in this manner have also been proposed by Rondelet, *L'Art de Bâtir*, tome iv.

The following rule may be used for finding the proper scantling or dimensions of these girders, viz. :—

Multiply one-and-a-half times the area of floor the girder supports in feet, by the length of bearing in feet; divide this product by the square of the depth in inches, and the quotient will be the breadth of the girder in inches.

The thickness of the bent pieces may be about one-fiftieth part of the bearing, and as many of them should be added as will increase the depth to that proposed, unless the whole depth of the curved pieces exceeds half the depth of the girder; and in that case straight pieces should be added to the under side, so as to make the whole depth of the straight parts exceed the depth of the curved parts. When pieces cannot be got sufficiently long for the girder, care should be taken to have no joints near the middle of the length in the lower half of the girder.

Fig. 45 shows a girder for a 40-feet bearing, with the lower half scarfed at *a*, with a plain butting joint in the curved part at *b*.

In the construction of floors it would be a great advantage to make each girder only half the breadth given by the rule, and to place them only 5 feet apart; to bridge the upper or floor joists over the girders, and notch the ceiling joists to the under side of them; and to omit the binding joists. There would be a great increase of strength and stiffness by adopting this method; and, in point of economy, it is decidedly preferable; but it requires of course a greater depth of flooring.

As the strain is always greatest at the middle of the length of a girder, it would be well to avoid making mortises there, if possible, either for binding joists or for any other purpose; and the most straight-grained part of the beam should be put to the under side.

Also, timber girders should not be built into the wall, but an open space should be left round their ends, either by laying a flat stone over them, or by turning an arch to carry the wall above.

Girders should be laid from 9 to 12 inches into the wall, according to the bearing.

BRESSUMMERS.

146.—When an opening is left in a wall for a door or window, the weight of wall above has to be supported by a *lintel* of wood. For ordinary windows and doors the depth of this lintel need not exceed 4 to 6 inches, the breadth being the thickness of the wall to be supported. But in the case of wide openings, as for bay-windows, folding doors, or shop fronts, a stronger beam must be used in order to prevent settlements in the wall above. A *bressummer* is a beam to carry the whole front of a house, its ends being usually supported on *story-posts* (Art. 133), which are tenoned into it. These beams may be formed in the same manner as described above for the girders of floors, and where the span does not exceed 10 or 12 feet, a piece of timber 10 inches square sawn down the middle, the flitches being reversed and bolted together, will suffice. But where there is a greater span than this, and the circumstances of the case do not admit of an increase in the depth and width, it is best to bolt a wrought-iron plate between the two flitches, and having exactly the same depth and

length. In order that both the wood and the iron should have their full effect in resisting the strain, the stiffness of the iron should just equal that of the wood; and as this is about twenty times as great as that of fir for the same bulk, the thickness of the plate should be one-twentieth of that of the wood; so that in the case of a beam of fir 10 inches broad, the iron plate should be half-an-inch thick. This arrangement will therefore just double the stiffness of the fir beam.

Since the load on a bressummer is generally distributed over its length we can find the scantling by the same formula as given for single-joisted floors (Art. 137), namely:

$$B \cdot D^3 = \frac{5}{8} a \cdot w \cdot L^3,$$

where $a = \cdot 01$ for fir, and w is the load on each foot length of the beam, when used without an iron plate. When a wrought-iron plate of the same depth as the beam and one-twentieth its thickness is placed between the two flitches, and the whole bolted together, the scantling can be obtained from the formula—

$$B \cdot D^3 = \frac{5}{16} a \cdot w \cdot L^3.$$

Example. Suppose a fir bressummer, or flitch-girder, 12 inches wide has to support a 14-inch brick wall 20 feet high over an opening 15 feet span; required the depth, first, without an iron plate, and secondly, with an iron plate of equal strength.

Taking the weight of brickwork at 112 lbs. per cubic foot, we have $w = 2{,}610$ lbs., and the first formula becomes

$$12\, D^3 = \frac{5}{8} \times \cdot 01 \times 2610\, L^3;$$
$$\therefore\ D = 1 \cdot 108\, L = 16 \cdot 6 \text{ inches.}$$

Secondly, when there is an iron plate, the second formula becomes

$$D^3 = \cdot 68\, L^3,$$
$$\text{or,}\quad D = \cdot 879\, L = 13 \cdot 2 \text{ inches.}$$

Bressummers may also be strengthened by means of an iron tension rod fixed between the flitches in the manner described in Art. 143.

BINDING JOISTS.

147.—In a framed floor the duty of the *binding joists* is to throw the weight of the floor upon the girders at intervals of about 6 feet, as explained in Art. 135. The weight of the floor is placed on the binders by the bridging joists, which being laid near together distribute the load uniformly over the whole length of the binders; and each binder has therefore to carry an area of flooring 6 feet wide by the distance apart of the girders as a

distributed load. Consequently, $w = 720$ L is the load in lbs.; and the equation for stiffness becomes

$$B \cdot D^3 = 4{\cdot}5\ L^3.$$

If the breadth is given, then we determine the depth from

$$D = \left(\frac{4{\cdot}5}{B}\right)^{\frac{1}{3}} L.$$

If the depth is given, then we have

$$B = 4{\cdot}5\ \frac{L^3}{D^3},$$

from which formula the Table of Scantlings (Table XXIV.) has been calculated.

These rules suppose the distance apart to be 6 feet; if the distance apart be greater or less than 6 feet, the breadth given by the rule must be increased or diminished in proportion. The breadth of the binding joists next the wall may be two-thirds of the breadth of the others; but in general they are made the same breadth, or such as are defective are selected for that purpose.

The binding joists may be from 4 to 6 feet apart, but should not exceed 6 feet; and about 6 inches bearing on the wall is sufficient.

The manner of framing binding joists into girders is shown by *fig.* 46; and in fitting them great care should be taken that both the bearing parts *a* and *b* should fit to the corresponding parts of the mortise. This is the most important part of fitting in a binding joist, yet is often the least attended to. The tenon should be about one-sixth of the depth, and at one-third of the depth from the lower side.

148.—Binding joists that have only to carry a ceiling may have their scantlings found by the same rule as that given above, only the load may be taken at 12 lbs. per square foot instead of 120 or $B \cdot D^3 = {\cdot}45\ L^3$. This will suffice for ordinary ceilings, and the scantlings in Table XXVII. are calculated from it; but where there is a large amount of ornamentation or panelling, the scantling must be made proportionally greater.

149.—The rule for the bridging joists is the same as that for single joisting (see Art. 137). They seldom need be more than 2 inches in thickness, except for ground floors, where they are laid upon sleepers; in which case the depth may be found to a breadth of 2 inches, and an inch may be added to the breadth, on account of the situation: as, when proper care is not taken to drain and ventilate the under side of a ground floor, the joists are subject to very rapid decay. It is a good practice to strew smiths' ashes, or even common ashes, under such floors, to prevent the growth of fungi. The ashes and scoriæ from a foundry, or any ashes that contain much iron, are the best. Mr. Batson found this an effectual remedy for the dry-rot. He filled a space below the floor, of 2 feet in depth, with anchor-smiths' ashes, and also charred the sleepers.* (See Section X, Art. 365.)

* *Transactions of the Society of Arts*, vol. xii.

CEILING JOISTS.

150.—Ceiling joists require to be no thicker than is necessary to nail the laths to; $1\frac{1}{2}$ to 2 inches is quite sufficient for that purpose.

The load being uniformly distributed over the length of each joist, the equation for stiffness is

$$B \cdot D^3 = \frac{5}{8} a \cdot w \cdot L^3,$$

and if we put $w = 12$ lbs., $a = \cdot 01$ for fir, we have

$$B \cdot D^3 = \cdot 075\ L^3, \text{ or } D = L \left(\frac{3}{40\ B}\right)^{\frac{1}{3}},$$

from which the scantlings in Table XXVI. are calculated. Therefore, to find the depth of a ceiling joist when the breadth and length are given, we have the following—

RULE. Divide half the length in feet by the cube root of five-thirds of the breadth in inches, and the quotient is the required depth in inches.

It is better to notch ceiling joists to the under side of the binding joists, and nail them, than to mortise and chase them in, because it requires less labour, does not weaken the binding joists, and the ceiling stands better. Oak is not so good a material for ceiling joists as fir, because it is more subject to warp, particularly if it be not well seasoned.

GENERAL REMARKS RESPECTING FLOORS.

151.—Girders should never be laid over openings, such as doors or windows, if it be possible to avoid it; and when it is absolutely necessary to lay them so, the wall-plates, or templets, must be made strong and long enough to throw the weight upon the piers. It is, however, a bad practice to lay girders obliquely across the rooms; it is much better to put a strong piece as a wall-plate.

In the bearings of floors the caution of Vitruvius must be attended to: that is, when the ends of the joists are supported by external walls of considerable height, the middle part of the joist should never rest upon a partition wall that does not go higher than the floor; for the unequal settlement of the walls will cause the floor to be unlevel, and most likely fracture the cornices.

Wall-plates and templets should be made stronger as the span becomes longer: the following proportions may serve for general purposes:—

	Inches.	Inches.
For a 20-feet bearing, wall-plates	$4\frac{1}{2}$	× 3
„ 30 „ „	6	× 4
„ 40 „ „	$7\frac{1}{2}$	× 5

Floors should always be kept about three-fourths of an inch higher in the middle than at the sides of a room when first framed; and also the ceiling joists should be fixed about three-fourths of an inch in 20 feet higher in the middle than at the sides of the room; as all floors, however well constructed, will settle in some degree.

In laying the flooring, the boards should always be made to rise a little under the doorways, in order that the doors may shut close without dragging; and at the same time it assists in making them clear the carpet.

The following remarks, from Evelyn's *Silva*, are also worthy of notice:—"To prevent all possible accidents, when you lay floors, let the joints be shot, fitted, and tacked down only the first year, nailing them for good and all the next; and by this means they will lie staunch, close, and without shrinking in the least, as if they were all of one piece; upon this occasion I have to add an observation that may prove of no small use to builders, that if one take up deal boards that may have lain in the floor a hundred years, and shoot them again, they will certainly shrink (toties quoties) without the former method."

FLOORS CONSTRUCTED WITH SHORT TIMBERS.

152.—There are many curious methods of constructing floors with short timbers, which cannot be passed over without notice, and yet are scarcely worthy of it; because they are seldom applied, as long as timber is always to be had. To those, however, who are more inclined to pursue curious than useful information, the following notices respecting such floors may be acceptable.

Let ABCD, *fig.* 47, *Plate* IV, represent the plan of a room, and let four joists be mortised and tenoned together, at *a*, *b*, *c*, and *d*, in the form shown in the figure; then it is evident that these joists will mutually support one another: each joist being supported at one end by the wall, and at the other by the middle of the next joist. This is one of the most simple forms, and will sufficiently explain the principle of constructing a floor of shorter timbers than will reach across the room.

The same thing may be done by mortising and tenoning the joists together in the form represented in *fig.* 48; and various other forms will readily suggest themselves, the manner being once understood.

A design for this kind of floor was given by Serlio;* and the celebrated mathematician, Dr. Wallis, has entered very fully into the investigation of the strength and disposition of these floors, in the first volume of his mathematical works. The researches of Dr. Wallis have been reprinted in Nicholson's *Architectural Dictionary*, Art. "Naked Flooring." The Dutch manner of framing these floors is given in Krafft's *Recueil de Charpente*, Part II.; and several forms are exhibited in Rondelet's *L'Art de Bâtir*, tome IV., &c.

153.—Perhaps the most singular floor that ever was constructed on a large scale, is one that was executed in Amsterdam, for a room 60 feet square, which has no joists whatever. There are very strong wall-plates on each side of the room, firmly secured with iron straps at

* *Tutte L'Opere di Architettura di Serlio da Scamozzi.* Venez. 1600, lib. i.

the angles, and rebated to receive the flooring. The flooring consists of three thicknesses of $1\frac{1}{2}$ inch boards. The first thickness is laid diagonally across the opening, the ends resting in the rebates of the wall-plates, and rising about $2\frac{1}{2}$ inches higher in the middle than at the sides of the room. The second thickness of boards is laid diagonally, but the direction is the reverse of the first thickness, and the two thicknesses are well nailed together. The boards of the third thickness are laid parallel to one of the sides of the room, and form the upper side of the floor, being also well nailed to the boards below. All the boards are grooved and tongued together, and form a solid floor, $4\frac{1}{2}$ inches in thickness.* This example shows how much may be accomplished by a well-disposed bond, and firm connection of parts. This floor partakes of the nature of a thin plate supported all round the edges; the strengths of plates supported in this manner are directly as the squares of their thicknesses, and they are equally strong to support a weight in the middle, whatever the extent of bearing may be; but when the load is uniformly distributed, the strength is inversely as the area of the space it covers.†

* Rondelet, *L'Art de Bâtir*, tome iv.

† Emerson's *Mechanics*.

TABLE XXIII.—*Scantlings of Girders, of Yellow Fir, for different Bearings, from* 10 *to* 36 *feet; Girders* 10 *feet apart from middle to middle.* (See Art. 139.)

Length of bearing in feet.	Depth 10 inches.	Depth 11 inches.	Depth 12 inches.	Depth 13 inches.	Depth 14 inches.	Depth 15 inches.	Depth 16 inches.	Depth 17 inches.	Depth 18 inches.	Length of bearing in feet.
	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	
10	7	5	4	4	3	$2\frac{1}{2}$	2	2	$1\frac{1}{2}$	10
11	8	6	5	$4\frac{1}{2}$	$3\frac{1}{2}$	3	$2\frac{1}{2}$	$2\frac{1}{2}$	2	11
12	$10\frac{1}{2}$	$8\frac{1}{2}$	$5\frac{3}{4}$	5	4	$3\frac{1}{2}$	3	3	$2\frac{1}{2}$	12
13	$12\frac{1}{2}$	10	$6\frac{3}{4}$	$5\frac{3}{4}$	5	4	4	$3\frac{1}{2}$	3	13
14	16	12	9	$7\frac{1}{2}$	6	5	$4\frac{1}{2}$	4	$3\frac{1}{2}$	14
15	19	15	11	$8\frac{1}{2}$	7	6	5	$4\frac{1}{2}$	4	15
16	24	17	13	10	$9\frac{1}{2}$	7	$5\frac{1}{2}$	5	$4\frac{1}{2}$	16
17		19	15	12	8	8	6	$5\frac{1}{2}$	5	17
18	.....	22	16	14	11	9	7	6	$5\frac{1}{2}$	18
19	.....	25	18	16	13	$10\frac{1}{2}$	8	7	6	19
20	.....		21	18	15	12	9	8	7	20
21	.....	.....	24	20	17	14	$10\frac{1}{2}$	9	8	21
22	.....	.....	27	22	19	16	12	10	9	22
23	.....	.....		24	21	18	14	$11\frac{1}{2}$	10	23
24	.....	.....	.....	26	23	20	16	13	11	24
25					25	22	18	15	12	25
26	Depth 19 inches.	Depth 20 inches.	Depth 21 inches.		27	24	20	17	$13\frac{1}{2}$	26
27					29	26	22	19	15	27
28	Breadth in inches.	Breadth in inches.	Breadth in inches.			28	24	21	17	28
29						30	26	23	19	29
30	20	18	15			32	28	25	21	30
31	21	19	16				30	27	23	31
32	22	20	17				32	29	25	32
33	23	21	18				34	31	27	33
34	25	22	19					33	29	34
35	27	23	20					35	31	35
36	29	25	22					37	33	36

To find the scantling for a girder of any length of bearing, look in either the right or left hand column for the bearing, and opposite in any of the other columns is the breadth, with the proper depth for that breadth at the head of the column; therefore such a breadth and depth may be selected as will be convenient for the intended purpose. Thus, for a 20-feet bearing a girder may be 21 inches in breadth and 12 inches deep; or the breadth may be 18 inches and the depth 13 inches, and so on; but where there is space to admit of a deep girder it requires less timber. A new series of depths begin for bearings above 29 feet.

This table is calculated by the equations in Art. 139, the load being taken at 120 lbs. on every square foot of flooring, or 1,200 lbs. on each foot length of girder, and distributed over the girder at intervals by means of binders about 6 feet apart. For warehouse floors the girders should be three times as strong as given above. The bearing is the distance between the centres of the supporting wall-plates; and the scantlings the least that will answer the purpose.

TABLE XXIV.—*Scantlings of Binding Joists, of Yellow Fir, for different Bearings, from 5 to 20 feet, when the distance from middle to middle is 6 feet.* (See Art. 147.)

Length of bearing in feet.	Depth 6 inches.	Depth 7 inches.	Depth 8 inches.	Depth 9 inches.	Depth 10 inches.	Depth 11 inches.	Depth 12 inches.	Length of bearing in feet.
	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	Breadth in inches.	
5	4	3	2	2	2	2	2	5
6	4½	4	3	2	2	2	2	6
7	7	5	4	2¾	2	2	2	7
8	10	7	5	3¾	2¾	2	2	8
9	15	9	6½	4½	3½	2½	2	9
10	20	12	8	5⅓	4½	3	2½	10
11				7½	5½	4½	3½	11
12	Depth 13 inches.	Depth 14 inches.	Depth 15 inches.	9½	7	5½	4	12
13	Breadth in inches.	Breadth in inches.	Breadth in inches.		9	7	5	13
14					11	8½	6½	14
15	6	5	4		13	10	8	15
16	7	6	5		15	12	9½	16
17	8½	7	6			14	11	17
18	10	8	7			16	13	18
19	12	10	8				15	19
20	14	12	10				17	20

To find the scantling for a binding joist for any bearing, look in either the right or left hand column of the table for the bearing in feet, and opposite the length of bearing, and under some one of the depths at the head of the columns, will be found the breadth required. Thus, if it be required to find the scantling for a binding joist for a 10-feet bearing, 9 inches is a depth that would be suited to the floor; then opposite 10 feet, in one of the side columns, and under 9 inches at the head of one of the middle columns, we find $5\frac{1}{2}$ inches, the breadth required. If 8 inches had been fixed upon for the depth, it would have required 8 inches in breadth to be equally as stiff as one 9 by $5\frac{1}{2}$. If the bearing be 19 feet, and 13 inches should be of convenient depth, then opposite 19 in the side columns, and under depth 13 inches, we find 12 inches, the breadth required.

This table is calculated by the rule $4{\cdot}5\,\frac{l^3}{d^3} = b$, where l is the length in feet, and d the depth, and b the breadth, each in inches.

TABLE XXV.—*Scantlings for Single Joisting, or Bridging Joists, of Yellow Fir, for different Bearings, from 5 to 25 feet; the distance from middle to middle 12 inches.* (See Arts. 137 and 149.)

Length of bearing in feet.	Breadth 1½ inches.	Breadth 1¾ inches.	Breadth 2 inches.	Breadth 2¼ inches.	Breadth 2½ inches.	Breadth 2¾ inches.	Breadth 3 inches.	Breadth 3½ inches.	Breadth 4 inches.	Length of bearing in feet.
	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	
5	4½	4¼	4	4	4	4	4	4	4	5
6	5	4½	4¼	4	4	4	4	4	4	6
7	5½	5¼	5	4¾	4¼	4¼	4¼	4	4	7
8	6¼	6	5½	5¼	5	4¾	4½	4¼	4½	8
9	7	7	6½	6¼	6	5¼	5	5	5	9
10	8	8	7	7	6½	6¼	6	6	5½	10
11	9	8½	8	7½	7	6½	6½	6½	6	11
12	9½	9	8½	8	8	7½	7	7	6½	12
13	10	9½	9	9	8½	8¼	8	7½	7	13
14	11	10	10	9¾	9¼	9¼	9	8	8	14
15	11½	11	10½	10	9¾	9½	9¼	9	8½	15
16	12¼	11½	11	10¾	10½	10	9¾	9½	9	16
17	12¾	12	11½	11¼	10¾	10½	10¼	10	9¼	17
18	13¼	12½	12	11½	11¼	10¾	10½	10¼	9½	18
19	14	13	12½	12	11½	11¼	10¾	10½	10	19
20	15	13½	13	12½	12	11½	11¼	11	10½	20
21	15½	14	13½	12¾	12½	12	11¾	11½	11	21
22	16	14½	14	13½	13	12½	12	11¾	11¼	22
23	17	15	14½	14	13½	13	12½	12	11½	23
24	18	16	15	14½	14	13½	13	12½	12	24
25	19	17	16	15	14½	14	13½	13	12½	25

To find the scantling for a joist for any bearing, look in either the right or left hand column for the given bearing, and opposite in any of the other columns will be found the depth, with the corresponding breadth at the head of the column; therefore such a breadth may be taken as is best adapted to the purpose required. Thus, for a 14-feet bearing, a joist 10 inches by 2 inches is of the same degree of stiffness as one 9 inches by 3 inches, or as one of any other depth opposite 14, with the breadth at the top of the column.

This table was calculated by the equation $\left(\frac{3\,l^3}{4\,b}\right)^{\frac{1}{3}} = d$. (See Art. 137.) The load is taken at 120 lbs. on each foot of length, for ordinary floors; for warehouse floors the load will be three times as great.

TABLE XXVI.—*Scantlings of Ceiling Joists, of Yellow Fir, for different Bearings, from* 4 *to* 15 *feet; distance from middle to middle* 12 *inches.* (See Art. 150.)

Length of bearing in feet.	Breadth 1½ inches.	Breadth 1¾ inches.	Breadth 2 inches.	Breadth 2¼ inches.	Breadth 2½ inches.	Breadth 2¾ inches.	Breadth 3 inches.	Length of bearing in feet.
	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	
4	2¼	2	2	2	2	2	2	4
5	2¾	2½	2	2	2	2	2	5
6	3	3	2½	2¼	2	2	2	6
7	3½	3	3	2½	2¼	2	2	7
8	4	3½	3	3	2½	2½	2½	8
9	4½	4	3½	3¼	3	3	2½	9
10	5	4½	4	3½	3¼	3	3	10
11	5½	5	4½	4	3½	3¼	3¼	11
12	6	5½	5	4½	4	3½	3½	12
13	6½	6	5½	5	4½	4	4	13
14	7	6½	6	5½	5	4½	4¼	14
15	7½	7	6½	6	5½	5	4½	15

In order to find the scantling of a ceiling joist for any bearing, look for the length of the bearing in either the right or left hand column, and opposite will be found the depth, with the breadth at the top of the column, containing the depth that is most convenient.

Ceiling joists should never have very long bearings, particularly those for ceilings next the roof of a house; as long joists are subject to warp, which breaks the plastering.

The distance from middle to middle should never exceed 12 inches, otherwise the bearing for the laths becomes too long. If the distance from middle to middle exceeds 12 inches double laths should be used.

This table is calculated by the rule $l\left(\frac{3}{40b}\right)^{\frac{1}{3}} = d$; where l is the length in feet, d is the depth, and b the breadth, in inches.

TABLE XXVII.—*Scantlings of Binding Joists, of Yellow Fir, that have to carry a Ceiling only, for different Bearings, from* 5 *to* 12 *feet; distance apart not more than* 6 *feet.* (See Art. 148.)

Length of bearing in feet.	Breadth 2 inches.	Breadth 2½ inches.	Breadth 3 inches.	Breadth 3½ inches.	Breadth 4 inches.	Breadth 4½ inches.	Breadth 5 inches.	Breadth 5½ inches.	Length of bearing in feet.
	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	
5	4	3½	3	3	3	3½	...	...	5
6	4½	4	3½	3¼	3	3	...	...	6
7	5	4½	4	3½	3¼	3¼	...	...	7
8	5½	5	4½	4	3¾	3¾	...	...	8
9	6	5½	5	4½	4¼	4	...	...	9
10	6½	6	5½	5	4¾	4½	4½	4¼	10
11	7	6½	6	5½	5¼	5	4¾	4¾	11
12	7½	7	6½	6	5¾	5½	5¼	5	12

This table is calculated from the formula $b \cdot d^3 = \cdot 45\, l^3$, allowing 12 lbs. per square foot for the weight of the ceiling and joists.

SECTION IV.

ON THE CONSTRUCTION OF ROOFS.

154.—A ROOF is intended to cover and protect a building from the effects of the weather, and also to bind and give strength and firmness to the fabric. To effect these purposes it should neither be too heavy nor too light, but of a just proportion in all its parts to the magnitude of the building. Mr. Ware observes, in his *Treatise on Architecture*, that in practice roofs are generally made too heavy, and that he will do a most acceptable service to his profession who shall show how to retrench and execute the same roof with the smallest quantity of timber; he will by this take an unnecessary load off the walls, and a large and useless expense from the owner.

The timber roofs meant to imitate the style of building called late Gothic, are generally made without horizontal ties at the feet of the rafters, as if intended to be supported by the walls, as an arch is supported by its abutments; the heavy walls they were in the habit of erecting, and the skilful disposition of buttresses in the Gothic, rendering ties unnecessary; although in the early periods of Gothic architecture, tie-beams were frequently used in the construction of the roofs.

The principles of construction in Gothic roofs bear a nearer analogy to masonry than to modern carpentry. It is true they sometimes erred in placing too great an oblique pressure against the walls; but in general we have more to admire than condemn in those celebrated buildings. The fashion of open timber-framed roofs originated about the reign of Edward III. as applied to great halls. They became common about 1400, and spans of considerable extent were roofed in a most judicious manner. The open timber roof of the later Gothic architects was generally executed in oak, and ornamented with bold and graceful mouldings, having richly carved ornaments at the joinings.* The most elaborate specimens are the halls at Christ Church, Oxford, and Hampton Court; that at Trinity College, Cambridge, is somewhat inferior: each of these is 40 feet span. The span of the roof of Westminster Hall is 68 feet. (See Art. 195.)

In the old Gothic buildings the roof is often of a high pitch, varying from 45° to 60°: its outline forms a striking feature, and is in general in graceful proportion with the magnitude of the building; sometimes, however, it presents too extensive a plain surface, of which we have a notable instance in the roof of Westminster Hall. A high roof is in perfect unison with the aspiring and pyramidal character of Gothic architecture; but in the opposite, though

* See Smith's *Specimens of Ancient Carpentry*, on thirty-six plates, 4to, 1786, where the forms of various roofs of this kind are given. Also Brandon's *Open Timber Roofs*.

80074

not less beautiful, style of the Greeks, it becomes a less conspicuous object; indeed many of the Grecian buildings were never intended to be roofed at all. Yet when a roof was necessary it was not attempted to be hidden, but constituted one of the most ornamental parts of the building. Of timber roofs we have no examples in Grecian buildings; but the beautiful stone roof of the Octagon Tower of Andronicus Cyrrhestes,* and that of the Choragic Monument of Lysicrates, are sufficient to show that they were more inclined to ornament than to hide this essential part of a building.

155.—In carpentry, the term *Roof* is applied to the framing of timber which supports the covering of a building. The *Pitch* of a roof, or the angle which its inclined side forms with the horizon, is varied according to the climate and the nature of the covering. The inhabitants of cold countries make their roofs very high, while those of warm countries, where it seldom rains or snows, make their roofs nearly flat. But even in the same climate the pitch of the roof has been subject to many variations. Formerly roofs were made very high, to prevent snow drifting between the slates, and perhaps with the notion that the snow would slide off easier; but where there are parapets, a high roof is attended with bad effects, as the snow slips down and stops the gutters, and an overflow of water is the consequence: besides, the water in heavy rains descends with such velocity that the pipes cannot convey it away soon enough to prevent the gutters being overflown; and the drift of snow is prevented by the greater care taken to render the joints close, and by boarding under the slates instead of using laths. In high roofs the action of the wind is one of the most considerable forces they have to sustain, and it appears to have been with a view of lessening their height that the Mansard or curb roof was invented. The quantity of room lost by a curb roof, the difficulty of freeing the gutters from snow, and the ungraceful effect of the roof itself, are objections that few would encounter to save the small difference between the expense of this and a common roof, especially now that experience has proved that roofs may be made of a much less height than our ancestors were in the habit of making them.

156.—The height of a roof, at the present time, is not usually above one-third of the span, and it should never be less than one-sixth. The ordinary pitch for slates is when the height is one-fourth of the span, or when the angle with the horizon is $26\frac{1}{2}°$.

The pediments of the Greek temples make an angle of from 12° to 16° with the horizon; the latter corresponds nearly with one-seventh of the span. The pediments of the Roman buildings vary from 23° to 24°; 24° is nearly two-ninths of the span, and is the angle Palladio recommends for roofs in Italy.

The kinds of covering used for timber roofs are copper, lead, iron, tinned iron, zinc, slates of different kinds, tiles, shingles,† reeds, straw, and heath. Taking the angle for slates to be $26\frac{1}{2}°$, the following table will show the degree of inclination that may be given for other materials:—

* Stuart's *Athens.*

† Shingles are now little employed in this country, though they appear to have been much used formerly (see Neve's *Builder's Dictionary*, Art. "Shingle"; Britton's *Archit. Antiq.*); and are still much in use in the West Indies and in America.

Kind of Covering.	Inclination to the horizon in degrees.	Height of roof in parts of span.	Weight upon a square foot of roofing.
	deg. min.		lbs.
Copper or lead	3 50	$\frac{1}{30}$	copper 1·00 / lead 7·00
Slates, large	22 · 0	$\frac{1}{5}$	11·20
„ ordinary	26 33	$\frac{1}{4}$	from 9·00 / to 5·00
Stone slate	29 41	$\frac{2}{7}$	23·80
Plain tiles...	29 41	$\frac{2}{7}$	17·80
Pantiles	24 0	$\frac{2}{9}$	6·50
Thatch of straw, reeds, or heath	45 0	$\frac{1}{2}$	straw 6·50
Force of wind does not generally exceed ...	...	...	40·00

157.—The force of wind, which is put down in the above table at 40 lbs. on the square foot of roofing, is in reality about the greatest pressure which in this country it ever exerts on a plain surface at right angles to the direction in which it is blowing; and as this direction is usually horizontal, or nearly so, it follows that the pressure which it exerts on a roof of high pitch must be much greater than on one of low pitch. The reader will find this matter discussed in *The Science of Building*, 2nd Edition, page 188, where it is shown that the pressure on a roof of 60° pitch is three-fourths of that on a vertical plane having the same area, when the wind is blowing horizontally; so that if we take 40 lbs. per foot as the pressure on a vertical surface, that upon a roof of 60° is 30 lbs. per foot; upon one of 45° it is 20 lbs.; while upon a roof of 30° it is only 10 lbs. It will, therefore, be generally sufficient if we include in the pressure of 40 lbs. per foot for the "wind" the effect of "other occasional forces," as the load of snow, for example, which in roofs of low pitch may sometimes amount to a very considerable quantity.

OF VARIOUS FORMS OF ROOFS.

158.—We have now to consider in detail the various forms of framing which have been employed in the construction of timber roofs; and these may be divided into two classes, namely, UNTRUSSED ROOFS, which consist only of plain sloping beams called RAFTERS, placed across from wall to wall, on which the covering is laid; and TRUSSED ROOFS, in which a system of framing called a TRUSS is introduced, upon which the above-named rafters, which receive the covering, are made to rest.

ON UNTRUSSED ROOFS.

159.—The simplest form of sloping roof, and one which is often used over openings of small span, is the LEAN-TO, SHED, OR PENT roof, which consists of a number of rafters (*fig.* 14) laid across from wall to wall, the ends of the rafters being notched down upon square pieces of timber called *wall-plates* laid horizontally in each wall, by means of which the weight of the roof is distributed uniformly along the walls. In this case the rafters are placed about 12 inches apart, and are laid over longitudinally with boards or battens to carry the slates, tiles, lead, or other covering. Where the roof has a pitch of 30°, the minimum *scantlings*, or dimensions of depth and breadth, of each rafter, are given at the end of the Section in Table XXXVII for different lengths of bearing.

This kind of roof is frequently found over the aisles of old Gothic churches; but when the span exceeds 8 or 10 feet it is usual to support the rafters upon stronger beams called *principals*, placed at distances apart of 10 or 12 feet a few inches below the rafters, and having the same slope; the rafters being made to rest upon the principals by means of a

FIG. 14.

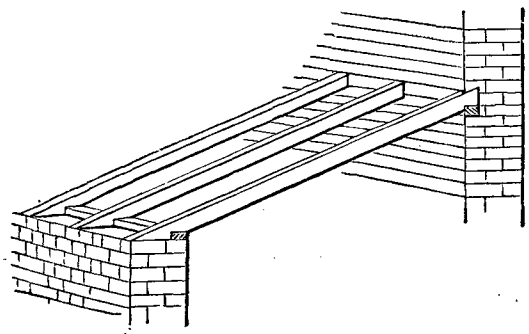
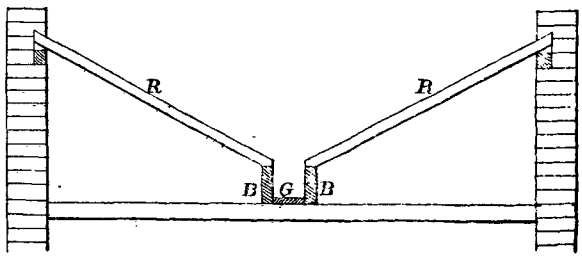


FIG. 15.



horizontal beam called a *purlin*, which is laid across about the middle of the beams and spiked thereto, the rafters themselves being also spiked to the top of the purlin. Such principals should be at least 7″ × 5″ for a span of 10 feet; 8″ × 5″ for one of 12 feet; 8″ × 6″ for one of 14 feet; and 9″ × 6″ for a span of 15 feet. The scantling of the purlin should be 7″ × 3″, 8″ × 3″, 9″ × 4″, and 9″ × 5″, respectively, for these several spans.

When we consider the action of the weight of the roof upon the walls which carry it, we see that a certain amount of horizontal thrust is produced upon them, both at top and bottom of the rafters, which tends to push the walls away from each other. If we call W the load on 1 foot linear of the roof, h the vertical height, and s the span, it is shown in Art. 35 that the horizontal thrust of the roof is W multiplied by s and divided by twice h, for every foot length of walling.

160.—The form known as the V- or M-ROOF, which is commonly used to cover rows of modern town houses (*fig.* 15), is a double SHED roof, in which the feet of the rafters R rest upon two bearers B, fixed from back to front of the house, forming with the piece G a

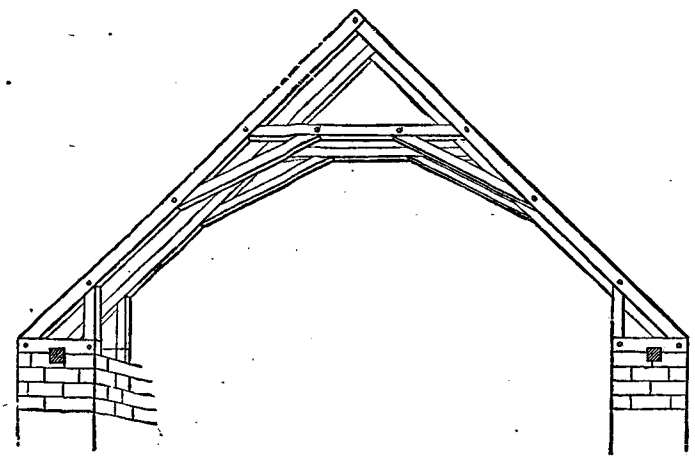
trough-gutter to carry off the rain-water, these timbers resting at their ends upon the back and front walls of the house, and upon any cross partition that there may be in the middle. The upper ends of the rafters are notched down upon wall-plates laid in the party walls.

In such gutters it is advisable to place a grating of wood or metal along the top of the trough, in order to prevent snow from filling it up, so that by resting on the grating it will gradually melt and pass off by the trough below without damaging the interior of the house.

161.—When the opposite walls of a building are of equal height, and the span between them exceeds 10 or 12 feet, the usual mode of forming the roof is by placing the rafters in pairs sloping upwards from the walls to a *ridge*, and abutting against a horizontal plank placed edgeways, and called a *ridge-piece*, as in *fig.* 1, Plate XXVI., which has the effect of keeping the vertices of the rafters all in one straight line, and of preventing the roof from getting out of shape. The feet of the rafters are either notched and spiked to a wall-plate at A and B, or else to the ends of the *ceiling-joists*, which act as ties to prevent the rafters from pushing out the walls. The thrust of this roof upon the walls can be found in the same manner as was mentioned above (Art. 159), namely, W multiplied by the half-span and divided by twice the height at the ridge. The scantling of the rafters for a roof of 12-feet span should be not less than $4\frac{1}{2}'' \times 2''$, and for 16-feet span $5\frac{1}{2}'' \times 2\frac{1}{2}''$, when the pitch is 30°. In the absence of ceiling joists at A and B, the thrust upon the walls may be counteracted, in a great measure, by the introduction of the *collar-beam* Cc (*fig.* 1, Plate XXVI.) about half-way up each pair of rafters, being halved and spiked to them in the manner shown on the figure, or more in detail by *fig.* 3, *Plate* XLVI. The scantling of the collar should be the same as that of the rafters.

This form of roof is, however, not to be recommended except where the span is very moderate, or the walls are sufficiently strong to bear the thrust, since the whole weight of such a roof is sustained by the parts of the rafters AC and B*c*; and when the roof has the weight of the covering upon it, it will settle in proportion to this weight, in consequence of the lower parts of the rafters bending at C, *e*, which will press out the walls. The reader who has thoroughly considered the effect of weight in producing flexure, will readily see that outward pressure against the walls with some spreading of the feet cannot be avoided in this construction, though it may be lessened by making the rafters very strong at the lower part. Failures, however, are often observed from adopting this form for a roof.

FIG. 16.

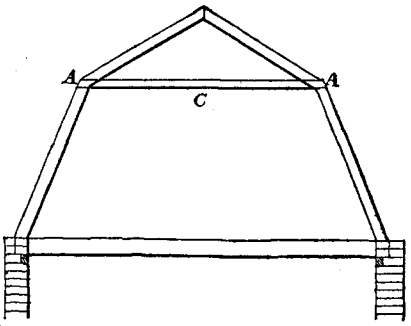


162.—A modification of the above-mentioned *collar-roof* is frequently observed in old Gothic buildings of moderate span, and is shown by *fig.* 16. Here the collar is

placed rather higher than the middle of the rafters, and an additional tie is introduced in the form of diagonal braces framed into both collar and rafter; the foot of each rafter is also further secured by being framed into a *wall-piece* which lies across the top of the wall, and has a vertical strut framed into its inner end, as well as into the under side of the rafter. All these pieces are *mortised* into each other and held together by oak pins driven through the *tenons*. As the timbers are, however, liable to shrink, it is advisable to secure the joints with iron straps or bolts in preference to the pins. (See Section IX.)

163.—The MANSARD or CURB roof, of which a section is shown in *fig.* 17, is designed with a view to providing habitable rooms in the roof. It consists of four rafters in place of the two used in an ordinary roof, forming an external angle A at their junction, the collar-beam C serving the double purpose of tying-in the feet of the top rafters, and of carrying the ceiling of the room below. The feet of the lower rafters are also secured to the ends of the floor joists, which prevents any outward thrust on the walls. The lower rafters are generally placed nearly vertical, or inclined at a high angle to the horizon. Some very large roofs of this kind were introduced into the palaces of France during the seventeenth century by the architect Mansard, and have been named after him ever since, the use of such roofs having continued down to the present time in most buildings of importance.

FIG. 17.



ON TRUSSED ROOFS.

164.—When the span of a roof is 20 feet or more, the rafters in the kind of roof described in Art. 161 must be increased in scantling, in order to prevent them from *sagging* in the middle. It is, however, more economical to introduce stronger rafters, called *principals*, at intervals of 10 or 12 feet, and to support the *common rafters*, on which the covering is laid, by means of *purlins* or beams laid horizontally across the *principal rafters*, on which the common rafters are notched. Thus in *fig.* 1, *Plate* VII., PP are the principal rafters, CC the purlins, *rr* the common rafters. The purlins are prevented from sliding by means of wood blocks, spiked to the upper side of the principal rafters, as shown in the figure. In order to prevent the principal rafters from thrusting out the walls, their feet are framed into the ends of the horizontal *tie-beam* A, in the manner shown on *Plate* XLVII., *figs.* 10, 11, 12, 13, being held down either by an iron bolt passing through the two beams, or by a strap of iron passed round the foot of the rafter, and secured by bolts through the tie-beam. The *pole-plate* on which the feet of the common rafters rest is notched down on the end of the tie-beam.

To prevent the sagging of the tie-beam, and also to enable the carpenter to reduce its scantling, it is held up in the middle by means of the *king-post* K, into the head of which the principal rafters are framed, as shown at large in *Plate* XLVIII., *fig.* 2. The lower end of the king-post does not rest on the tie-beam, but is made an inch or two short of it, the

tie-beam being drawn up to the post by means of an iron bolt or a strap passed under it and bolted to the king-post with key-wedges.

To prevent the principal rafters also from sagging it is usual to insert the struts BB, which are tenoned into the rafters, and also into the foot of the king-post, on which a shoulder is formed in order to receive them.

The piece of framing above described is the simplest form of what is called a TRUSS, and embodies all the principles upon which the most complicated pieces of framework are constructed.

165.—Since the king-post is subjected to a tensile strain only, it is often found advantageous to use a wrought-iron rod instead of the piece of timber; in which case a cast-iron head is used to receive the heads of the principal rafters (see Section IX.), through which the *king-bolt* is passed, having a head at top and a screw-nut at bottom to hold up the tie-beam through which it passes, as shown by the example in *fig.* 1, *Plate* VIII. In this example the feet of the rafters are let into cast-iron shoes, fixed on the top of the tie-beam, which prevents them from crippling it. Another peculiarity of this example is the absence of common rafters, purlins 30 inches apart being substituted for them, on which the boarding is nailed.

166.—When the span of a roof exceeds 30 feet, another form of truss is adopted, as shown by *fig.* 2, *Plate* VII. Here the tie-beam is held up in two places by means of *queen-posts*, Q, D, which are themselves supported by the principal rafters P, P, and the horizontal *straining-beam* S, being framed into their heads. The horizontal thrust of the struts B, B, is counteracted by a *straining-sill* laid on the top of the tie-beam, between the feet of the queen-posts.

ON THE FORMS OF TRUSSED ROOFS FOR DIFFERENT SPANS.

167.—A roof for a span of from 20 to 30 feet may have a KING-POST truss of the form shown in *Plate* VII., *fig.* 1. Within the limits above stated the purlins do not become too wide apart, nor the points of support for the tie-beam; and in the Table XXVIII., at the end of the Section, the scantlings of the timbers are given according to the length and bearing of the different parts. The figure is drawn with a parapet on one side and eaves on the other side. *Fig.* 1, *Plate* VIII., is an example of a king-post roof in which iron is used in combination with timber, and the boarding for the slates or lead is laid directly on purlins without the interposition of common rafters.

The scantlings given in the tables have been carefully calculated for different kinds of roofs by help of the method described in Art. 17, and from the formulæ in Arts. 203 to 214.

168.—For spans exceeding 30 feet, and under 46 feet, the QUEEN-POST truss exhibited in *Plate* VII., *fig.* 2, is extremely well adapted; each purlin is supported, consequently there are no cross strains on the principal rafters; and the points of support divide the tie-beam into three comparatively short bearings. The scantlings may be had from the Table XXIX., at the end of the Section.

The sagging which usually takes place from the shrinking of the heads of the queen-posts

may be avoided by letting the end of the principal rafter abut against the end of the straining beam S, and notching pieces and bolting them together in pairs at each joint. The side marked D of the figure is supposed to be done in this manner. This is further illustrated in Section IX. (see Art. 317), and is shown in detail on *Plate* XLVIII, *fig.* 6.

The same method is applicable to any other roof, therefore it appeared better to explain it under the head of JOINTS than under any particular design.

169.—When the span exceeds 45 feet, and is not more than 60 feet, the truss shown in *Plate* IX., *fig.* 1, is sufficiently strong for the purpose, and leaves a considerable degree of free space in the middle. For this span the tie-beam will most likely require to be *scarfed*, by one or other of the methods shown on *Plates* XLVI. and XLVII., and as the bearing of that portion of the tie-beam between *a* and *b* is short, the scarf should be made there. The middle part of the tie-beam may be made stronger by bolting the straining-sill *s* to it. The scantlings may be got from the Table XXX., at the end of the Section; and the principles of scarfing and joints are detailed in Section IX.

170.—A truss for a roof from 75 to 90 feet span is shown by *fig.* 2, *Plate* IX. In this truss the *straining-sill s* should be tabled or keyed, and bolted to the tie-beam in the manner that has already been proposed for increasing the depth of girders (see Section III., Art. 145). This truss nearly resembles the roof of the Birmingham Theatre, designed by Mr. G. Saunders, but since destroyed by fire. The Birmingham roof, however, has the queen-posts closer together than in our illustration, their distance apart being $19\frac{1}{2}$ feet, and there is no king-truss above the straining-beam, the upper part of the rafters being stiffened by a collar-beam. The tie-beam is $15'' \times 15''$, and cocked down on an oak corbel $9'' \times 5''$; principal rafters $9'' \times 9''$; straining-beam $12'' \times 9''$; king-post D, $9'' \times 9''$; queen-post Q, $7'' \times 9''$; braces $9'' \times 9''$ and $6'' \times 9''$; purlins $7'' \times 5''$. An illustration of this roof will be found in *Carpentry and Joinery*, Weale's series, No. 182.* The span is 80 feet.

By omitting, or rather reducing, the upper part of the truss in *fig.* 2 to the same form as that in *fig.* 1, the truss would answer for a bearing of from 60 to 75 feet. The scantlings may be had from the Table XXXI., at the end of the Section.

But when the span is so very wide, unless the building be of a proportional height, the roof exhibits such an immense mass of plain surface, that it destroys the architectural effect of the building; besides, it is difficult to light the large space in the roof in any way that would not be objectionable on account of the external appearance.

171.—To avoid a large expanse of roof, the truss may be of the form shown in *Plate* X, *fig.* 1, from Price's *British Carpenter*. A roof of this form is called an M-roof. It would do for a span of from 55 to 65 feet; but it would be better to make the top flat and cover it with lead, and adopt the truss represented in *Plate* IX., *fig.* 2, as the space gained in the roof would amply repay the expense of the lead flat. The scantlings of the M-roof may be got from the Table XXXII., at the end of the Section.

172.—In spans exceeding 65 feet, the truss that was adopted in the construction of Drury Lane Theatre, in 1793, is, in respect to form, perhaps one of the best that can be devised of its kind. *Plate* X., *fig.* 2, shows a roof on the same principle, of which the scantlings may be obtained from the Table XXXIII., at the end of the Section. One part of the

* Crosby Lockwood & Co.

principal truss is shown with a queen-post, the other with suspending pieces, as described in Art. 306, Section IX. The middle part of the principal tie-beam is supposed to be built as a girder.

In the roof of Drury Lane Theatre, which, however, was burnt down several years ago, the principal rafters P have braces to stiffen them from the feet of the queen-posts, as in *fig.* 1; and the distance between the queen-posts is 32 feet, the space being utilised for rooms.

The span is 80 feet and the scantling of the timber is as follows:—tie-beam, 15″ × 12″; queen-posts, 15″ × 12″; principal rafters, 14″ × 12″; braces to principal rafters, 8″ × 12″; king-posts, 12″ × 7″; tie-beams to king-posts, 10″ × 7″; straining-beam, 12″ × 12″; purlins, 9″ × 5.″ An illustration of this roof will be found in *Carpentry and Joinery*, Weale's series, No. 182.*

EXAMPLES OF TIE-BEAM ROOFS WHICH HAVE BEEN EXECUTED.

The roofs here selected for description present some interesting specimens of the art of carpentry, as applied in the framing of several English and foreign roofs, both of ancient and modern construction.

ROOF OF THE OLD BASILICA OF ST. PAUL AT ROME.

173.—The truss exhibited in *Plate* XI., *fig.* 1, is one of the trusses of the late Basilica of St. Paul at Rome, executed about 400 years ago, but destroyed by fire several years since. There was another kind of truss in the same roof which was much older, having been executed in 816, during the pontificate of Leo III.; but the form was not so good as the one here given. These trusses are double: that is, each consists of two similar frames placed 14·9 inches apart; and these double trusses are about 10·5 feet apart. The principal rafters abut against a short king-post *k*. Between the trusses a piece of timber, S, is placed, and sustained by a strong key of wood passing through it and the short king-posts; this piece sustains the tie-beams by means of another strong key at *a*. The tie-beams are in two lengths, and scarfed together, as shown by *fig.* 2. The scarf is held together by three iron straps.

Scantlings of the Timber.

	Inches.		Inches.
Tie-beams, *t*.....	22·5	by	14·9
Principal rafters, *p*...	21·75	by	14·9
Auxiliary rafters, *b*...	13·8	by	13·3
Straining beam, C ...	14·9	by	12·8
Purlins, *d*.....	8·5 square, and 5 feet 7 inches apart.		
Common rafters	5·3	by	4·25, and 8·5 inches apart.

* Crosby Lockwood & Co.

This roof was executed in fir, and the span 78·4 feet. The common rafters were covered with strong tiles, about 12 inches by 7, forming a kind of pavement set with mortar in the joints. On this pavement a kind of plain tiles with ledges were laid, and the joints covered with crooked tiles, as is represented by *fig.* 3. From this description some notion may be formed of the load upon this roof.*

The roof is simple and strong; the method of sustaining the middle of the tie-beam is ingenious; and the covering, though heavy, is well calculated to preserve a uniform temperature within the building in a warm climate; and a similar covering might be often adopted with much advantage in our own variable one, as a means of excluding cold.

There is a similar roof over the Church of Sta. Maria Maggiore at Rome, of which the span is nearly 56 feet and the scantling of the tie-beams 15 inches by $10\frac{1}{2}$ inches.†

ROOF OF THE THEATRE D'ARGENTINA AT ROME.

174.—One of the trusses of the Theatre d'Argentina is represented in *Plate* X., *fig.* 4. The span is 80·5 feet, and the slope of the roof 24 degrees. The tie-beam is in three pieces, scarfed and strapped together; and the principal rafters are each in two pieces, also scarfed and strapped together. The common rafters are from 10 to 11 inches apart, and are supported by 12 purlins on each side; these rafters support a heavy tile covering. The tie-beams are supported by stirrups of iron, in a very judicious manner. They differ considerably from any other example, except that of the Théâtre de Odéon, which is a close imitation of it, to a 77·8 feet span. The roof of the Theatre d'Argentina is executed in fir, that of the Odéon in oak; both of them have to sustain the machinery of the theatre, besides the ceilings and covering.*

There appears to be too much strength in some parts of this roof; but the design is extremely simple, and well adapted to the purpose.

ROOFS AT ANCONA AND FLORENCE.

175.—*Plate* XII. shows detached parts of the roof of the new Theatre of Ancona, the Palazzo Vecchio, and of the Cathedral of Florence.

The iron rod and strap at the ends of the tie-beam of trusses to roof over the new Theatre at Ancona, were noted down for their novelty and peculiarity; but the utility of the arrangement is not apparent.

The drawing of part of the roof over the Hall of the Palazzo Vecchio at Florence shows a satisfactory repair done a few years prior to 1826, under the superintendence of Signor Fantasticci, the Grand Duke's architect. The repair was rendered necessary by the decay of the ends of the timbers, which, from neglect of the gutters, had been long exposed to wet. Two stone corbels were inserted into the wall beneath the truss,

* *L'Art de Bâtir.* † See Krafft's *Carpentry*, Part V.

a strong oak template was laid on these, and the sound part of the foot of the tie-beam brought to its proper firm bearing on this template by means of large wedges.

The sketch of the scarf in the great wooden tie worked into the dome of the Cathedral at Florence shows a singular specimen of old carpentry, very simple and strong. The sketch is necessarily imperfect, as the only part of this tie which is visible is at the windows, and there it is for the most part cased with metal, in order to protect it from the wet that might drive in. It is therefore only to be presumed that underneath the arrangement is similar to what can be seen at the top.

ROOF OF LEGHORN CATHEDRAL.

176.—*Plate* XIII. This roof is supposed to be the work of Vasari; the trusses are in pairs about 12 inches apart: one of them appropriated to the support of the roof, and the other to that of the ceiling, which is of prodigious weight. The timbers of this roof are larger, and their direct strength more depended on, than a modern builder would deem advisable. The arrangement of them, however, is simple and unobjectionable in principle. The scarf may be regarded as one of remarkable strength. The span is 58 feet. The pairs of trusses are $15\frac{1}{2}$ feet apart.

ROOF OF THE ACADEMY, FLORENCE.

177.—*Plates* XIV. and XV. show a modern roof constructed over the Saloon at the Academy of the Fine Arts at Florence. Two very flat queen-post trusses bear nearly the whole weight of the roof, covered ceiling, and sky-light.

There is nothing very remarkable in their construction, further than as successful examples of modern carpentry in Italy. In England, however, at the present day, a builder would probably prefer the use of iron girders in such a case.

ROOF OF PARKHURST PRISON.

178.—*Plate* XVI. shows the truss of the roof over the Great Hall of the Juvenile Prison at Parkhurst, in the Isle of Wight. The area roofed over is 100 feet by 40 feet; it has neither inside supports, nor lateral buttress, nor abutment of any kind. This truss is peculiar for its economy of materials, and for the avoidance of all unnecessary side-grain abutment of the timbers, a frequent source of failure in roofs executed in wood. The span is 39 feet 3 inches; the angle of pitch being 27°.

ROOF OF CHRIST'S HOSPITAL HALL, LONDON.

179.—*Plates* XVII. and XVIII. show the details of the roof of the Hall of Christ's Hospital, London. The principals (A, *Plate* XVIII.) in this construction are trusses in

the ordinary way, with queen-posts, which are here, however, of iron. An additional support at the bearing of the tie-beams is also obtained by means of the iron standards and shoes. The timber being thus protected from the damp arising from the stone and brickwork which come in contact with them, must contribute greatly to the durability of the structure.

These iron standards are concealed by the ornamental spandril brackets in the Hall. The distance between these principals is 17 feet. Trusses B, C, and D are thrown across in five places, to carry the rafters which run longitudinally; there being no purlins necessary, as is usual in this mode of construction.

The central truss D is delineated in the second *fig.*, *Plate* XVIII., with the dimensions of the several parts; and the trusses C and D are shown in *Plate* XVII., as also the main rafters and filling-in beams between the trusses B, C, D, to carry the ceiling joists.

Means are provided, as shown in the drawing, at every point of screwing up the several trusses, whereby to preserve their proper degree of stiffness.

As the rafters run longitudinally, and the boarding transversely, no opposition is presented to the fall of the water from the roof by the starting of the joints of the boarding.

Great attention has been paid to the scantling of the different timbers; the roof is covered with lead, and stands remarkably well. Its length is 187 feet, and span 51 feet. It is constructed of Baltic timber. The angle of pitch is 17°.

GREAT NORTHERN RAILWAY STATION, LONDON.

180.—*Plate* XIX. shows the trussed roof of the Goods Depôt at the King's Cross Station of the Great Northern Railway, erected in 1852, by Mr. Lewis Cubitt, architect. The span being 78 feet, it was necessary to scarf the tie-beam, and to support it in five places by vertical tie rods, which in this case are of wrought iron, passing through cast-iron heads. The angle of pitch is 28°, and the covering is laid upon purlins or horizontal rafters which rest directly on the principal rafters. The ends of the tie-beam and feet of the rafters rest in a cast-iron shoe bedded on the wall upon a stone template. The scantlings of the principal timbers are as follows:—Tie-beam 12″ × 12″, rafters and straining-beam 12″ × 14″, struts 8″ × 8″, purlins 11½″ × 4″, and 10″ × 4″.

* DESCRIPTION OF STORE-ROOM ROOF AT BOMBAY.

181.—The accompanying *fig.* 18 represents a truss of 40 feet span, supporting, with other trusses placed at intervals of 10 feet, a roof which slopes 30° from the horizon, and has an extreme span from eaves to eaves of 50 feet. The tie-beam is supported at equal intervals of 8 feet, and the purlins and wall-plate are also separated by equal distances of 6·35 feet. The struts, rods, and queen-posts are so disposed as in a great

* Colonel Waddington's Paper on the "Doctrines of Carpentry," Vol. X, *Papers of the Royal Engineers*.

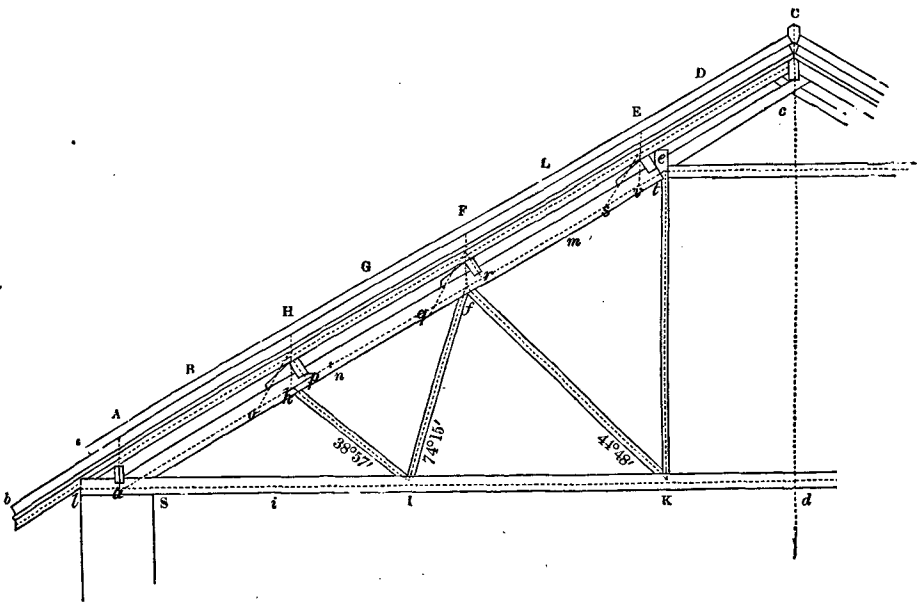
measure to neutralize pressure on the principal rafters, except in direction of their length; and the common rafters are supposed to extend in one length from ridge to eaves and to be 15 inches apart. The battens are each $2'' \times \frac{3}{8}''$, and their edges 2 inches apart, covered by a double bamboo mat; the eaves single-tiled, the lower row being laid in chunam, the rest of the roof double-tiled, and the ridge of chunam.

Scantlings of Timber for a Trussed Roof having a clear span of 40 *feet.*

	Tie-beam.	Queen-post.	Principal.	Struts.	Purlin.	Common rafter.	Straining beam.
Figure 18 ...	$5'' \times 5''$	$5'' \times 2\frac{2}{5}''$	$5'' \times 6''$	$\left\{\begin{matrix} 3\frac{1}{2}'' \times 4'' \\ 2\frac{1}{4}'' \times 2\frac{3}{4}'' \end{matrix}\right\}$	$4\frac{1}{4}'' \times 6\frac{3}{4}''$	3″ diameter	$5'' \times 4\frac{1}{2}''$

Trusses nearly resembling that represented in *fig.* 18 were used in the construction of the camp equipage store-room at Bombay, in 1839, and are found perfectly efficient.

FIG. 18.



Calculation of the Weight of the Roof.

Weight of 1 *square foot double-tiled, exclusive of purlins and truss.*

22 tiles, each 10″ long, $3\frac{1}{4}''$ mean diameter, and weighing, when wet, 20 oz.	=	27·5	lbs.
1 square foot of doubled bamboo mat, weighing 7 oz.	=	0·4375	,,
$3'' \times 2' \times \frac{3}{8}''$ = 27 cubic inches teak battens, of specific gravity 745 = 11·64 oz. ...	=	0·7275	,,
$\frac{4}{5}' \times 3''$ diameter = 67·85856 cubic inches teak rafter, of do. = 29·256 oz.	=	1·8285	,,
$2\frac{2}{5}$ batten nails, length $1\frac{3}{4}$ inch, 100 per lb.	=	0·0240	,,
Total	=	30·5175	,,

And the weight of 1 square foot, single-tiled, is less than the above by the weight of half the number of tiles = (30·5175 lbs. — 13·75 lbs. =) 16·7675 lbs.

Weight of one chunam eave.

10 running feet of chunamed eaves, tiles exclusive, at 9 lbs. per foot	=	90	lbs.
1 teak eaves board, 10′ × 4″ × ¾″ = 360 cubic inches.			
Deduct for the displaced batten, 10′ × 2″ × ⅜″ = 90 „			
270 „	=	7·275	„
Total	=	97·275	„

Weight of chunam ridge.

10 running feet chunam ridge, including ridge-tiles, at 28 lbs. per foot	=	280	lbs.

Weight of ridge-pole.

1 teak ridge-pole, 10′ × 2½″ × 7½″ = 2250 cubic inches	=	60·6283	lbs.
16 rafter nails, length 6 inches, 8 per lb.	=	2·0000	„
1 ridge nail, length 9 inches, 4 per lb.	=	0·2500	„
Total	=	62·8783	„

Weight of one purlin and block.

1 teak purlin, 10′ × 4¼″ × 6¾″ = 3442·5 cubic inches	=	92·7612	lbs.
1 teak block, 1′ × 5″ × 3½″ = 210 cubic inches	=	5·6586	„
8 rafter nails, length 6 inches, 8 per lb.	=	1·0000	„
1 purlin nail and 2 block nails, length 9 inches, 4 per lb.	=	0·7500	„
	=	100·1698	„

Weight of the truss.

1 teak tie-beam, 45′ × 5″ × 5″ = 13500 cubic inches	=	363·7696	lbs.
2 principal rafters (each 19′ × 5″ × 6″) = 13680 cubic inches	=	368·6197	„
2 upper ditto (each 5′ × 3″ diam.) = 848·232 cubic inches = 22·8563 lbs.			
With 1 rafter ... ... = 0·125 „	=	22·9813	„
1 straining beam, 7′·8 × 5″ × 4″·5 = 2106 cubic inches	=	56·7480	„
2 queen-posts (each 9′·6 × 5″ × 2″·4 and 0′·8 × 5″ × 5″) = 3244·8 cubic inches = 87·4340 lbs.			
With iron plates (each 2′ × 1″ × 1¼″), iron bolt 6½″ × ⅝″ diameter, and nut, altogether 9·445 cubic inches, at 4·5 oz. per cubic inch = 5·3128 lbs.	=	92·7468	„
2 upper struts (each 8′·25 × 3″·5 × 4″) = 2772 cubic inches	=	74·6940	„
2 lower struts (each 4′·2 × 2″·25 × 2″·75) = 623·7 cubic inches	=	16·8062	„
2 iron rods (each 7′·2 × ¾″ diam. with nut) = 76·9 cubic inches	=	21·6280	„
Total	=	1017·7936	„

Calculation of the Weight of a Plastered Ceiling.

Weight of square foot.

1′ × 1½″ × 3½″ = 63 cubic inches teak joist ... ... ½′ × 1½″ × 2½″ = 9 cubic inches batten, nailed to tie-beam 12′ × ⅜″ × ⅝″ = 33·75 cubic inches ceiling battens ...	105·75 cubic inches ...	=	2·8495 lbs.
⅛th joist nail, length 6 inches, 8 per lb.		=	0·0250 ,,
⅛th batten nail, length 3 inches, 30 per lb....		=	0·0066 ,,
12 ceiling nails, 240 per lb.		=	0·0500 ,,
1 square foot chunam plaster = 11 lbs. 6 oz.		=	11·3750 ,,
Total		=	14·3061 ,,

From the foregoing Articles we find the weight of roof, *fig.* 18, between truss and truss, to be as under, exclusive of the truss, purlins, and ridge-pole.

The span from *l* to *l* = 45′ × 1·1547 for the slope × 10′, the distance of the trusses, is = 519·615 square feet of double tiles, which × 30·5175 lbs. weight per square foot gives	=	15857·35 lbs.
The width of the two eaves = 5′ × 1·1547 × 10′ = 57·735 square feet of single tiles, which × 16·7675 lbs. weight per square foot, is	=	968·07 ,,
The weight of the chunam ridge is	=	280·00 ,,
,, ,, two chunam eaves	=	194·55 ,,
Total	=	17299·97 ,,

which weight may be thus divided:

Weight of the chunam ridge at C	=	280 ,,
Ditto from C to E = 54·86 square feet × 30·5175 lbs. = 1674 lbs. which × 2 ...	=	3348 ,,
Ditto from E to F = 63·5 ,, × ditto = 1938 ,, ,, × 2 ...	=	3876 ,,
Ditto from F to H = 63·5 ,, × ditto = 1938 ,, ,, × 2 ...	=	3876 ,,
Ditto from H to A = 63·5 ,, × ditto = 1938 ,, ,, × 2 ...	=	3876 ,,
Ditto from A to *l* = 14·44 ,, × ditto = 441 ,, ,, × 2 ...	=	882 ,,
Ditto from *l* to *b* = 28·86 ,, × 16·7675 lbs. = 484 ,, ,, × 2 ...	=	968 ,,
Ditto of two chunam eaves	=	194 ,,
Total	=	17300 ,,

ROOFS WITH CURVED RIBS.

182.—There is a considerable degree of difficulty in executing a roof when there are a great number of joints, and the timbers of large dimensions; and the shrinkage of the king- or queen-posts often produces considerable derangements in the truss. It is obvious that to make principal rafters in a continued series of pieces abutting end to end against one another would remedy these defects. These pieces would then form a kind of curve, and according to the degree of neatness required, might be made regular, or left with projecting angles, as is shown by *fig.* 1, *Plate* XX. These pieces might either be bolted, or mortised and put together

with wooden keys, as represented in *fig.* 2. The length of the pieces would be determined by the form of the curve; crooked timber would be preferable for the ribs where it could be procured, as the joints should be as few as possible, and they should be crossed, like the joints in stone work.

Plate XX, *fig.* 3, shows a roof constructed in this manner. Each of the supports for the tie-beam marked S, S, &c., consists of two pieces, one put on each side of the rib, and notched both to the rib and to the tie-beam. The pieces are bolted together, as is shown by a section to a larger scale, through one of these pairs of suspending pieces, in *fig.* 4. This mode of construction admits of a much firmer connection with the tie-beam than is procured by the ordinary mode, and the number of suspending pieces may be increased at pleasure. The best situation for the suspending pieces is at the joints of the curved rib.

The weight of the roof being very nearly uniformly distributed, the form of the curved rib should be a parabola (see Section I., Art. 65); and as this curve is easily described with sufficient accuracy for this purpose, it is best to adopt it; because in that case, the strain from the weight of the roof and ceiling will have no tendency whatever to derange the form of the rib; and its depth will always be sufficient to withstand any partial force to which a roof is ever likely to be exposed. Consequently, when the rib is of a parabolic form, diagonal braces will be unnecessary as regards the constant strain; nevertheless, if they be added, they will increase the strength to resist any partial strain in a very considerable degree.

To construct the parabola, let AB, *fig.* 5, be drawn for the upper side of the tie-beam, and AC, CB, for the under side of the common or small rafters. Then divide AC and CB each into the same number of equal parts (an even number is to be preferred), and join the points 1 and 1, 2 and 2, &c.; then the curve formed by these intersecting lines will be the parabola required.

But it will be found that this curve scarcely differs from a circular arc that rises half the height of the roof: therefore either may be used.

If a lantern or any other structure is to be raised on the top, a hyperbolic curve should be adopted; which admits of a considerable increase of pressure at the crown.*

The scantlings of the curved ribs are given in Table XXXV., at the end of the Section. The tie-beam will require to be scarfed for large spans, and would be best made in two thicknesses, and joined so that the scarfs should not be opposite one another.

183.—Smaller roofs might be constructed in a similar manner, at a comparatively small expense. But in these, instead of forming the rib of short pieces, it might be bent by a method somewhat similar to that employed for bending ship timber, as described in Art. 112.

If the depth of a piece of timber does not exceed a hundred and twentieth part of its length, it may be bent into a curve that will rise about one-eighth of the span without impairing its elastic force. And if two such pieces be laid one upon the other, and then bent together by means of a rope fixed at the ends, they may be easily be brought to the form of the required curve, by twisting the rope as a stone sawyer tightens his saw, or as a common bow saw is tightened. The pieces may then be bolted together; and if this operation be performed in a workmanlike manner, the pieces will spring very little when the rope is gently

* Simple methods of describing these curves are given in Nicholson's *Carpenter's New Guide*, and also in Tarn's *Practical Geometry*. Crosby Lockwood & Co.

slacked; and it is advisable to do it gradually, that the parts may take their proper bearing without crippling.

Otherwise, a piece of about one-sixtieth part of the span in thickness may be sawn along the middle of its depth, with a thin saw, from each end towards the middle of the length, leaving a part of about 8 feet in the middle of the length uncut. The pieces may then be bent to the proper curve, and bolted as before.

In either case the rise of the ribs should be half the height of the roof; and they should be bent about one-fourth more, to allow for the springing back when the rope is taken off. A roof of this kind for a 30-feet span is shown by *Plate* XX., *fig.* 6. The suspending pieces are notched on each side, in pairs, and bolted or strapped together, as shown by *fig.* 4.

The advantages of this roof consist in the small number of joints in the truss, in being able to support the tie-beam at any number of points, in admitting of a firm and simple connection with the tie-beam, and in avoiding the ill effects attending the shrinking of king- or queen-posts. The scantlings are given in Table XXXIV., at the end of the Section.

184.—The largest timber roof ever designed was that for the Riding-House at Moscow, in 1790, for Paul I., Emperor of Russia. It is represented by *Plate* XXI. The span was 235 feet, and the slope of the roof about 19 degrees. The principal support of this immense truss consisted in an arch or curved rib of timber, in three thicknesses, indented together, and strapped and bolted with iron. The principal rafters, and the tie-beams, were supported by several vertical pieces notched to the curved rib, and the whole stiffened by diagonal braces. The disposition of the parts of this roof is extremely ingenious; but as it appeared to be too slight for the immense extent of the span, it was proposed to add another curved rib in the situation shown by the dotted lines. A reference to Art. 23 will show the impropriety of adding material so near to the neutral line of the framing; a like want of attention to principle is sometimes found in a first design; a roof designed by Bettancourt for a riding-school, as given by Krafft, is an example.

The external dimensions of the building were 1,920 feet by 310 feet; it was lighted from the top by a lantern, and there was a gallery round the inside of the building for spectators.*

185.—A remarkable example of the use of laminated ribs for roofs is seen in the King's Cross terminus of the Great Northern Railway in London, the roof of which is formed in two spans of 105 feet each and 800 feet in length, by means of semi-circular ribs formed of $1\frac{1}{2}$ inch planks bent to the curve laid flat upon each other and strongly bolted together. A transverse section of this roof is shown on *Plate* XXII., and a longitudinal section with details of the ribs on *Plate* XXIII. The ribs are placed at intervals of 20 feet apart, and the rigidity of the arch is procured by crossing the grain of the wood in the formation of the ribs, so that they preserve their curvature and have no tendency to straighten out. The lower portion of each rib is, however, firmly bolted to a cast-iron spandril, which extends upwards to a distance of 40 feet from the springing, so that one-half of the arched rib is held firmly by the ironwork. The covering of the roof is supported by purlins 8 feet apart, upon which the boarding of the lower portion and the glazing of the upper portion is laid.

This roof, however, may be regarded as a partial failure, the arched ribs having sunk considerably at the crown; and it has been found necessary to replace the wooden ribs over the arrival platform with others of wrought iron.

* Krafft's *Recueil de Charpente*, or Rondelet's *L'Art de Bâtir.*

186.—The most usual method of constructing curve ribs is that introduced by De Lorme (see Art. 219), in whose system the planks are used in short lengths and bolted together with their depth vertical, and arranged so as to break joint with each other. There is an example of this kind of roof in that over the principal room of the Pantheon in Oxford Street, London, the transverse section of which is shown on *Plate* XXIV., and the longitudinal section on *Plate* XXV. The clear span of the arched rib is 38 feet 2 inches. This roof is cylindrical, and is supported by nine semi-circular ribs 11 feet 6 inches apart. Each rib is in three thicknesses, bolted together; the middle thickness is of 5-inch teak, the side thicknesses or flitches are of $2\frac{1}{2}$-inch fir, the minimum depth being 16 inches; the pieces of timber forming these thicknesses are scribed on the under side to the curve of the roof (and ceiling), but the top edge is left straight; therefore at their abutting ends they are considerably broader than at their middle. Each abutment of every piece throughout every rib has a shoe of cast iron interposed. Iron bolts connect the three thicknesses together at each end, with a washer connecting each pair of bolts as explained on the section.

The ribs rest alternately on the pillars (hereafter described), and on the centre of the longitudinal plate extending the whole length of the roof. (See *Plate* XXV.) In the former case the ribs are framed into strong upright pieces, each of which becomes the king-post of a semi-truss. These semi-trusses, besides carrying the timber of the roof and ceiling over the galleries, are calculated to receive the lateral thrust of the semi-circular roof; a large cast-iron shoe, laid upon a stone template, receives the end of the tie-beam of these semi-trusses next the outer wall; the object of this shoe being to prevent the possible decay of this end of the beam from affecting the stability of the roof.

There is also a cast-iron shoe receiving the other end of this beam, which is formed with sockets and flanges so as to receive and connect together the king-post and tie-beam of the above-named semi-truss, and the longitudinal plate alluded to above, and the head of the great iron upright or pillar. The chief use of this iron shoe is to prevent the lateral compression of the timbers, and to prevent the natural shrinkage of the horizontal plate from letting down the roof.

The intermediate ribs (those which do not rest on the iron pillars) rest on another iron shoe, which is fitted on to the head of an upright piece that rests on the centre of the longitudinal plate; but the bearing is thrown on to the iron pillars by stout braces framed into the said upright piece and longitudinal plate.

It will thus be seen that throughout the skeleton of this roof there is no case of any important timber resting with its *end* upon the *side* of any other piece, but that they all bear with an *end-grain* abutment, so that the cracks and failures arising from the necessary shrinkage, as well as from the lateral compression of the timbers, are avoided. This was a precaution rendered necessary by the very large scantlings of the timbers, and by the discharge of the whole weight of roof and ceiling being thrown on so few points of support. The circular part of the roof is covered with copper laid on diagonal boarding, which is supported on rafters notched on to the great ribs, and running longitudinally. The roofs over the sides or galleries are slated, with a flat plaster ceiling; the ceiling of the circular part is deeply panelled, the main ribs forming the core for the cradling. The enrichments are of papier-mâché, a material that was well adapted for the large architectural ornaments, from its lightness, and from the safety with which it could be screwed up to the timbers.

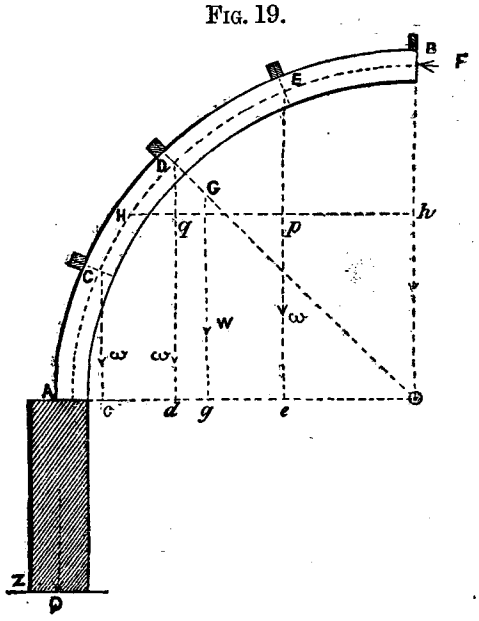
The longitudinal plate above alluded to consists of two pieces of fir, each 12 × 6, bolted together: the bearings between the iron pillars are reduced by braces (not shown on the plate), which discharge the bearing on to the iron pillar, and at the same time receive the wood cradling for the imitations of stone spandrils. Each end of this plate is let into the wall, and is received by a corbel of teak wood, on to which it is bolted and cocked down.

ON THE THRUST OF ARCHED RIBS.

187.—As it is of importance to determine the strength of such ribs as we have described in Art. 186, and also to know what amount of thrust they produce upon the walls or supports, we will give the method of calculating these quantities as explained in *The Science of Building*.

Let AB (*fig.* 19) represent the half of such a rib, carrying the load of a roof by means of purlins at C, D, E, and B, and resting on a pier at A. Let W be the weight of the rib itself, acting at G its centre of gravity, OG being ·90D by Art. 31, the line BEDC passing through the centre of the rib; let w be the load on each purlin, acting at B, E, D, and C. At B only $\frac{1}{2}\,w$ must be taken. Then if F is the horizontal pressure at B of the other half rib, we have to take the moment of F about A as equal to the sum of the moments of the weights; therefore the equation,

FIG. 19.



$$\mathrm{F} \times \mathrm{BO} = \mathrm{W} \times \mathrm{A}g + w\,(\tfrac{1}{2}\,\mathrm{OA} + \mathrm{A}e + \mathrm{A}d + \mathrm{A}c),$$

determines the horizontal thrust F, which we can now consider as acting at the base A of the rib, and tending to overturn the pier about its outer edge Z. To resist this thrust we have Q the weight of the pier and $\mathrm{W} + \frac{7}{2}w$ the weight of the roof acting down the centre of the pier; so that its thickness t that will suffice to produce equilibrium may be found from the equation,

$$(\mathrm{Q} + \mathrm{W} + \tfrac{7}{2}\,w)\,\frac{t}{2} = \mathrm{F} \times \mathrm{AZ}.$$

If the pier is thicker than the dimension found by this equation, the structure will be in a condition of stability.

In order to determine the safe-load that may be put on the rib itself, we take moments of the loads at D, E, and B about H, where the strain is greatest, H being the middle point between C and D; and equate the sum of these moments with the *moment of resistance* M of the section of the rib, namely,

$$\mathrm{M} = w\,(\tfrac{1}{2}\,\mathrm{H}h + \mathrm{H}p + \mathrm{H}q) = 15\,b\,.\,d^2.$$

by Arts. 106 to 109, if fir is the wood used for the rib, for safe-load; b and d being in inches, and the other dimensions in feet; w being in lbs. As an example, let the rib have an internal radius of 10 feet, and an external one of 11 feet, its depth and breadth being 12 inches; let W = 500 lbs., w = 2,000 lbs.; then we find Ag = 4·3, Ad = 3·6, Ac = 1·3, Ae = 7, OB = 10·5, OA = 11. Therefore the first equation becomes

$$F \times 10{\cdot}5 = 500 \times 4{\cdot}3 + 2000\,(5{\cdot}5 + 7 + 3{\cdot}6 + 1{\cdot}3)$$
$$\text{or } F = 3{,}520 \text{ lbs.}$$

Let AZ = 10 feet, and the weight of a cubic foot of the pier be 120 lbs. Then if Q is the weight of a pier 1 foot broad, we have Q = 1200 t; and the second equation becomes

$$1200\frac{t^2}{2} + 7500\,\frac{t}{2} = 35200,$$
$$\text{or } 12t^2 + 75t - 704 = 0;$$
$$\therefore t = 5{\cdot}2 \text{ feet.}$$

In order to obtain stability the thickness of the pier must exceed 5·2 feet, when the length is 1 foot. If we suppose the ribs to be 10 feet apart, and each to be supported by a continuous wall 10 feet long, the equation becomes

$$120\,t^2 + 75t - 704 = 0,$$

which gives t = 2·125 feet for equilibrium; the quantity of walling, however, is in this case four times as great as in the former. For the strength of the rib at the point H, we find the *moment of strain*, when w = 2,000 lbs., to be 20,250, while the *moment of resistance* of the rib from the expression M = 15bd^2, is 25,920; so that in this case the rib is stronger than necessary in about the ratio of 13 : 10. If we require to know the amount w that can safely be laid on such a rib, we obtain it from the equation,

$$w = \frac{25920}{10{\cdot}125} = 2{,}530 \text{ lbs.}$$

To determine b when w = 2,000 lbs. and d = 12 inches, we have—

$$b = \frac{2000 \times 10{\cdot}125}{{\cdot}15 \times 144} = 9\tfrac{1}{2} \text{ inches.}$$

COLLAR-BEAM ROOFS.

188.—In the construction of modern roofs of large span a continued tie at the foot of the rafters is necessary (though sometimes it has been omitted), wherever the lightness of the walls renders them incapable of sustaining much lateral pressure; and this pressure is entirely removed by a straight tie-beam.

Leaving out the tie-beam gains only a very small space in height, and this space may

generally be obtained, without injury to the external effect of the building, by raising the walls a little higher: this, therefore, ought generally to be done: for a roof without such tie must be subject to the following defects:—

In the first place, let *fig.* 1, *Plate* XXVI., represent a roof with a collar-beam C*c*; the whole weight of such a roof will be sustained by the parts AC, B*c*, of the rafters; and the roof will settle in proportion to the weight of the covering, in consequence of the lower parts of the rafters bending at C, *c*, which will press out the walls. We may therefore expect failures from adopting this form of a roof, except where the span is very moderate, or the walls are sufficiently strong to resist the outward thrust.

189.—In wider spans another mode of construction has been employed, which, though better than the foregoing, is not a good one, from the powerful strains that are excited in it by the oblique disposition of the beams. To show the nature of these strains, we take *fig.* 2, *Plate* XXVI., from Price's *British Carpenter*, the author of which has said much in praise of it, apparently without being aware of its mechanical defects. The essential parts of this roof are contained in *fig.* 8, *Plate* I.: and by comparing the strains produced by the weight in that figure, with the strains when CA is in a horizontal position, it will be found the strains are more than doubled by the oblique position of CA. Returning again to the section of the roof in *Plate* XXVI., let the vertical line *a*E be drawn, *fig.* 2, and let *a b* upon this line represent the weight of half the roof; also draw *c b* parallel to AC, and *c a* parallel to AD. Then the weight and pressures will be measured by *a b*, *b c*, and *a c*. But if there had been a tie-beam AB, the pressures produced by the same weight would have been only *b d* and *a d*: hence it appears that they are nearly doubled, while the space gained in the middle in height amounts only to about one-ninth of the span. To gain this small advantage we encounter the difficulty of making a firm connection of the ties at C, with the certainty of a considerable change of figure from flexure, the settlement from the number of the joints, and the magnitude of the strains. It also must be remembered, that whatever degree of settlement takes place will tend to move out the walls, and that the same degree of settlement will produce a greater effect in thrusting out the walls in proportion as CE is greater. Having thus pointed out the defects of this kind of roof, we must leave the reader to judge for himself on the propriety of adopting it. If wrought-iron ties are substituted for the beams AC, BC, the feet of the rafters can be tied as effectually as with a horizontal tie-beam.

190.—*Plate* XXVII. shows a section of a collar-beam roof over the Exchange at Genoa. It is a very remarkable piece of carpentry for the multiplicity of iron ties with which the whole is held together. The chief object of all these elaborate expedients for keeping the work together appears to have been to allow of the omission of the tie-beam: an object so often sought at the expense of all constructive propriety and simplicity. This Hall is about 96 feet by 66 feet.

191.—In some examples attempts have been made to give strength to collar-beam roofs by making the beams AC, BC, *Plate* XXVI., *fig.* 2, cross each other, and connecting them to the principal rafters; the construction is not so improved by the alteration as to prevent the application of every objection here urged against the roof; for the objections are to the principle, and apply to a roof formed out of one piece of iron as well as to a wooden one; but of course the more imperfect the construction, the more the walls will be forced out by the flexure and settlement. An example of this form of roof is seen in *Plates* XXVIII. and

XXIX., which show the trusses of a roof over the Duke of Modena's Cavallarizzia, or Riding-House attached to his Palace at Modena. The area roofed over is about 180 feet by 50 feet.

There is in this truss little regard paid to economy of materials; and the principle on which it is constructed must be considered defective, being without either tie-beam or collar, to prevent the spreading of the rafters. The object, however, that was aimed at is gained—viz., the ceiling being carried up into the roof. No signs are perceptible of failure having occurred, although the six oak braces have much the appearance of being subsequent additions. The cutting of the principal rafter in two for the sake of introducing the head of the queen-post is peculiar, but must be considered as a fault, on account of the mischief that would result from the unavoidable shrinkage of so large a timber as the queen-post. Great pains seem to have been bestowed, in this roof, on the framing of the several timbers into each other. The truncated truss (*Plate* XXVIII.) it is probable would scarcely have held together but for the iron tie that is introduced.

In contrast to the above-named piece of framing a tie-beam roof is given in *Plate* XXX. which shows the truss of a roof at Modena, over a Riding-House for the public service, built in 1826 at the expense of the Duke, under the superintendence of Signor Soli. This is framed on a sounder and safer principle than the former, and with a somewhat less superfluity of timber.

192.—The centre aisle of churches being often higher than the side ones, a collar-beam roof may be employed with the same effect as when the tie-beam continues through, by connecting the lower beams, by means of braces, to the upper one, so that the whole may be as a single beam. To illustrate this principle, we have drawn the roof in *fig.* 3, *Plate* XXVI., which is for a church similar to that of St. Martin-in-the-Fields, London. Here the lower ties, B, B′, are so connected to the collar-beam AA′, by means of the braces b, b', that the foot of the principal rafters P, P′, cannot spread without stretching AA′. The iron rods a, a', perform the office of king-posts to the ties B, B′; and are better than timber, because the shrinkage of timber ones would be particularly objectionable in that situation. The oblique positions of d d' will render them effectual in opposing the spread of the rafters. A somewhat similar roof was erected by Sir C. Wren over the church of St. Andrew's, Holborn, 64 feet wide, except that the central truss has three king-posts instead of queens.

193.—Roofs without a tie-beam are frequently constructed over docks and slips, in order to protect ships from injury by the weather during the time they are building, or while they are in dock, or on the slips for repair. They differ from ordinary roofs chiefly in magnitude; and being erected on standards with considerable elevation in the centre, they are much exposed to be racked and strained by high winds.

The materials used for covering have generally been such as could be adopted with the least first expense, such as tarred canvas, or tarred paper on boards; but in some instances they have been covered with thin copper; in others slate has been used; and, eventually, it will be found the best economy to employ slate on boarding.

The construction of the framing should be designed as an arch to carry the weight without a tendency to change its figure; with depth of framing, or ties and braces, sufficient to render the roof capable of resisting the utmost force of winds. *Fig.* 25, *Plate* III., shows one of the methods of construction in use. The stability of this form of framing is discussed in Arts. 59, 60. A roof of this kind was erected over a dock at Plymouth, having a clear span of 95 feet.

The roof over the west slip of the King's Dockyard at Deptford is nearly of the following dimensions:—

Total width	146	feet
Breadth between standards	68	„
Clear height in the middle	64	„ above ground line.
Height of the standards	49	„ above ground line.
Height of eaves	16	„ above ground line.
Standards, 2 beams	12	inches square bolted together.
Framing of trusses	$5\frac{1}{2}$	inches thick.
Purlins	6	inches × 4 inches.
Rafters	5	„ × $2\frac{1}{2}$ „

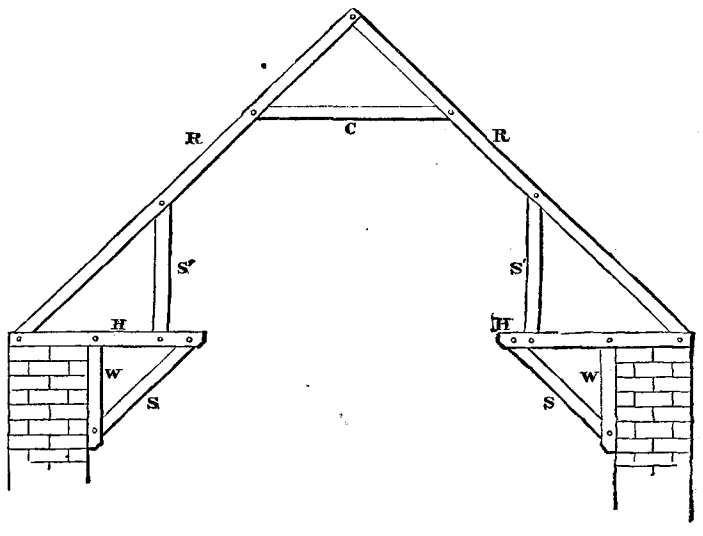
This roof is boarded with $\frac{3}{4}$-inch boarding for paper covering.

HAMMER-BEAM ROOFS.

194.—A peculiar form of roof truss, in which the horizontal tie-beam is dispensed with, was much employed by the English builders of the fourteenth and fifteenth centuries, and is now frequently adopted by modern architects for Gothic buildings. The general principle of its construction is shown by *fig.* 20, although a great variety of design was displayed in the ancient roofs, no two of which were exactly alike.

The principal rafters, R, R, are framed at their feet into horizontal beams, H, H resting on the top of the walls and called HAMMER-BEAMS, which occupy the place of the tie-beams in ordinary roofs.

FIG. 20.



In order to prevent the rafters from thrusting the hammer-beam outwards, a diagonal strut S is framed into the inner end of each, and also into a vertical *wall-piece* W, which is itself framed into the under side of the hammer-beam. A vertical strut S′ is also placed between the rafter and the end of the hammer-beam. By this means a considerable amount of the thrust of the rafters is thrown vertically down the walls. There will, however, always remain sufficient horizontal thrust to push out the walls, if they are not built sufficiently strong, or supported by external buttresses.

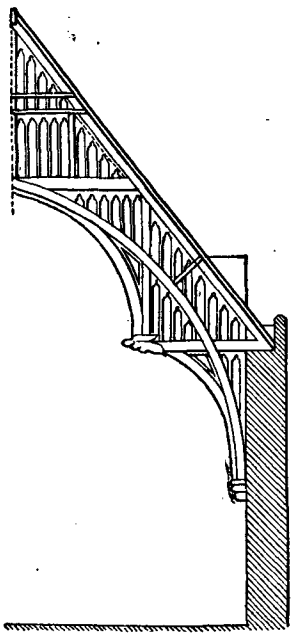
The principle of the construction of these roofs is based on the property of the triangle, that whilst the lengths of the sides remain the same, the angles which they make with each other are unchangeable; and in this case all the pieces of timber are arranged to form the sides of triangles, so that the joints are all rendered immovable. Thus what

might at first sight have the appearance of being a load upon the roof is, in fact, its strength and stability.

195.—The most remarkable specimen of hammer-beam roof, as well as the largest and most magnificent, is that of Westminster Hall, shown on *fig.* 21.

The angle of this roof is formed at a pitch of 52°, the length of the rafters being about three-fourths of the entire span, which is 68 feet; the length of the hall is 238 feet, and divided into twelve bays by thirteen principals. To provide against lateral pressure, we find trusses, or principals, raised at distances apart of about 18 feet, throughout the whole length of the building. The trusses abut against the solid parts of the walls between the windows, which are strengthened in those parts by arch buttresses on the outside. Every truss comprehends one large arch, springing from corbels of stone, which project from the walls at 21 feet below the base line of the roof, and at nearly the same height from the floor. The ribs forming this arch are framed at its crown into a collar-beam, which connects the rafters in the middle of their length. A small arch is turned within this large one, springing from the inner ends of the hammer-beams; and supported by two brackets, or half-arches, issuing from the springers of the main arch. By this construction of the trusses, each one acts like an arch; and by placing their springers so far below the top of the walls, a more firm abutment is obtained; subordinate timbers co-operate to transfer the weight and pressure of intermediate parts upon the principals; and thus the whole structure reposes in perfect security, after more than four centuries from its first erection. Great rigidity appears to be given to the main arch by the two small arches in combination with the hammer-beam, thereby giving it the form of a truss, and preventing any great horizontal thrust from falling upon the walls.

FIG. 21.



196.—The roof over the Great Hall at Hampton Court somewhat resembles that of Westminster in the principles of its construction, although in this case there is no main arch, but an arched rib springs from the inner end of each hammer-beam, and a curved strut below carries the thrust well down the wall, and rests on a stone corbel 12 feet below the hammer-beam; while a straight strut, or brace, is fixed from the end of the hammer-beam next the wall to the vertex of the arch, so as to form a kind of truss of two triangles, by which great stiffness is given to the framing. The span of this roof is 40 feet, and the pitch 50°, the hammer-beams projecting 10 feet from the walls. It has two collar-beams, the upper one being fixed to the top of the main rafters, and a flat termination being given to the roof, so as to resemble a curb roof.

The roof of the Hall at Eltham, in Kent, has hammer-beams projecting one-fifth of the span, which is 36 feet, the pitch being 50°; in this case the arched struts are so flat that they throw the load on the top of the wall instead of bringing it down low upon it.

Fig. 4, *Plate* XXVI., is a sketch of the roof of Westminster School, from Smith's *Specimens of Ancient Carpentry*. It shows the most usual form of the roofs of Gothic halls, as they differ more in the tracery and ornaments than in the essential parts of the framing. The

timbers are so disposed as to throw the pressures a considerable way down the walls, and at the same time nearly in a vertical direction. Indeed, considering the effect that was intended to be produced, and the massive walls for abutments, the arrangement of the parts is worthy of much praise.

197.—Many excellent examples of the hammer-beam roof of moderate span are to be found over the ancient churches of Norfolk and Suffolk. In some cases we find that there is no proper collar-beam, the arched strut itself acting in that capacity, as in the roof of Wymondham Church, Norfolk, which has a span of 24 feet, and a pitch of only 38°. In this roof, each of the hammer-beams projects one-fifth of the span, and from their inner ends spring curved ribs meeting at a point about 2 feet below the vertex of the rafters, and a curved strut also springs from a corbel 6 feet below the hammer-beam. We find another roof of similar construction at Trunch Church, Norfolk, with a span of 19 feet, and a pitch of 48°; here the hammer-beams have a very great projection, and the scantling of the principal timbers is 10″×10″. There is also the roof of St. Stephen's, Norwich, with a span of 17 feet, and a pitch of 45°, the scantling of whose principals is 12″ × 11″; also that of Palgrave Church, Suffolk, with a span of 20 feet, and a pitch of 43°, where the hammer-beam projects only 3 feet, and the scantling of the principals is 13″ × 10″. Another similar roof, having a span of 25 feet, is seen at South Creak Church, Norfolk; and one of 29 feet span, with a pitch of 40°, at Worstead, Norfolk, where the hammer-beams project only 4½ feet from the wall.

198.—Among the hammer-beam roofs which are provided with straight collar-beams may be mentioned that of Freslingfield Church, Suffolk, whose span is 20 feet, and pitch 39°; here the hammer-beams project 3½ feet, and are very much tilted upwards, and a flat arch springs from their inner ends to the centre of the collar; the scantling of the collar-beam is 14″ × 8″, and that of the other principal timbers, 10″ × 8″. Another example of this class of roof is at the church of Capel St. Mary, Suffolk, where the collar is at two-thirds the height from the hammer-beam, which latter projects only 2 feet from the wall, and forms the base of an arched rib rising to the middle of the collar; the span of this roof is 18 feet, and the pitch 46°, the scantling of the principal beams being 10″ × 8″.

199.—In some cases we find a second hammer-beam introduced half-way between the one which rests on the wall and the collar-beam; such a roof does not gain anything in strength from the second hammer-beam with its brace and strut, which, moreover, add considerably to its load upon the walls. One of the largest of these double hammer-beam roofs is that over Knapton Church, Norfolk, of which the span is 30 feet and the pitch 38°; the scantling of the collar-beam being 15″ × 7″, and of the other timbers 12″ × 10″. Other double hammer-beam roofs of small span are to be seen over the churches of Woolpit, Bacton, and Grundisburg, in Suffolk.

In all these ancient roofs we find the timbers fastened together by means of wooden pins driven through the tenons; no ironwork in the shape of bolts or straps being employed in their construction.

Illustrations of the above-named church roofs will be found in Brandon's *Open Timber Roofs*, and *Analysis of Gothic Architecture*.

200.—Among hammer-beam roofs which have been erected in recent times is that over the Hall of the Manchester Assize Courts, designed by Mr. Waterhouse, of which the span

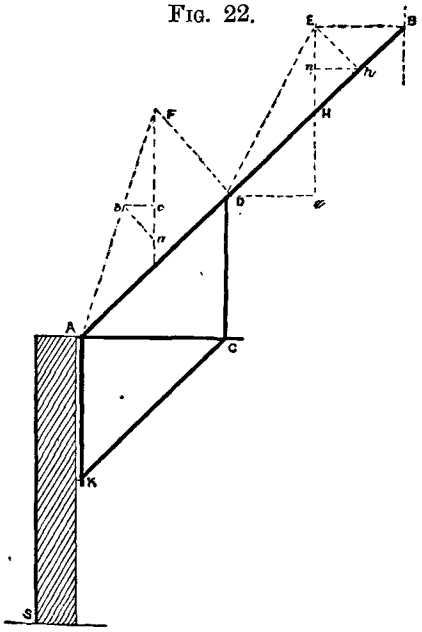
is 48½ feet and the pitch 55°, the distance apart of the principals being 14 feet. The hammer-beams in this case extend about one-fourth of the span on each side of the Hall, and are supported below by curved struts springing from stone corbels half-way between the floor and the eaves; while from the inner ends of the hammer-beams spring arched ribs meeting at the centre of the collar-beam, which is placed half-way up the principal rafters, and is held up by a king-post truss. Longitudinal latticed timber-trusses are supported on the inner ends of the hammer-beams, and run the whole length of the building, their ends resting on gable walls, so as to relieve the side walls of some portion of the thrust.

These lattice girders are 16½ feet deep, and carry the king-post principals mentioned above, which support the upper portion of the roof.

A description of this building will be found in the *Transactions of the Institute of British Architects* for 1865.

201.—The following method of calculating the strains on a hammer-beam roof is taken from *The Science of Building*. Let *fig.* 22 represent the half transverse section of such a roof, in which the horizontal collar-beam (C, *fig.* 20) is omitted. Since the two triangles ADC, AKC, are perfectly rigid, we have only to consider the thrust arising from the load on BD, which we call W, and suppose to act at its centre H. We can determine the relations of the forces as in Art. 35, by drawing BE horizontally to meet the vertical EH; and if E*e* represents the load W, the line ED will represent the pressure at D in magnitude and direction, and D*e* the horizontal component P acting as a thrust at D. By means of the rigid piece of framing DK this thrust is brought down to the point K, and the lower this point is down the wall the less will be the tendency of the thrust to overturn it. The force P at K has a moment P × KS about the outer edge S of the wall, which is counteracted by the moments of the weight of the half truss and of the wall itself. If W is the weight of the upper part of the roof above D, *w* that of the frame DK, and Q the weight of the wall itself, whose thickness is *t*, we may consider all these forces as acting down the middle of the wall; and in order that the structure may be in a condition of stability we must have

FIG. 22.



$$(W + w + Q)\frac{t}{2} > P \times KS.$$

The strains in the pieces AC, CK, may be determined as previously shown in Art. 20. To find the compression down the strut DC, draw E*h* perpendicular to BD, and *h n* horizontal, then E*n* will represent the vertical pressure at D from the rafter DB. To find the pressure arising from AD, draw DF perpendicular to AD, meeting the vertical through the middle point of AD at F; draw FA; let F*a* represent the weight of the rafter AD, draw *a b* parallel to DF, and *a b* will be the reaction at D of AD; draw *b c* horizontal, and *a c* will represent the

pressure down DC arising from AD; so that $En + ac$ will be the compression in DC. The line Fc is the vertical pressure arising from AD upon the wall at A. In this manner the strains upon any part of the framing can be compared with the weight of the load upon the rafter.

ON PROPORTIONING THE PARTS OF ROOFS.

202.—The proportions of the timbers of a truss depend so much on the design of the framing of a roof, that it would be impossible to furnish rules which should apply directly to all cases: nevertheless, by considering a few combinations, the method that may be adopted will be seen, and consequently may be applied to designs made on other principles than those already shown. The scantlings given in the Tables at the end of the Section have, however, been calculated by a method similar to that given in Art. 17, whereby the exact amount of strain to which each beam is subjected can be determined, and the required strength to resist that strain ascertained by the rules given in Section II.

OF KING-POSTS, SOMETIMES CALLED CROWN-POSTS.

203.—The king-post is intended to support half the weight of the tie-beam and the ceiling which is fastened to it; and by means of the braces to support part of the weight of the roof; it is marked K in the roofs, *fig.* 1, *Plate* VII., and *fig.* 2, *Plate* IX. The weight suspended by the king-post will be proportional to the span of the roof; therefore to find the scantling we proceed as follows:—

The strain on the foot of the king-post K arising from the braces B, B, *fig.* 1, *Plate* VII., can be found when we know the amount of load sustained by the purlin C. In *fig.* 6, *Plate* I., let AC represent a rafter, BC a strut, and AB a king-post; and take the vertical line Cc to represent the load on the purlin at C, which we may suppose to equal half the weight of the covering on one side of the roof, or $\frac{W}{2}$. Draw cb parallel to AC, and ca to BC, and ab horizontal. Then Cb represents the compression on the brace, which can be resolved into the vertical and horizontal components, half Cc and half $a\,b$, the former of which represents the vertical strain produced by each brace on the king-post. The horizontal component is counterbalanced by that of the brace on the opposite side of the king-post. The strain on the king-post will be entirely tensile, and its scantling may therefore be determined by the rules given in Art. 79, when the load which it has to sustain is known; the strength being as the area of section. It will be seen from the above diagram that the vertical strain on the king-post arising from the brace increases with the increase of the angle of inclination of the brace with the tie-beam.

The scantlings given in the tables are for roofs in which the height BC is one-fourth of the span AA′ or half AC, or the angle of pitch is 27°; in which case the length of the rafter AB is 1·12 × AC. Let AC $= \frac{1}{2}$ S, AB = L, then L = ·56 S. If W is the load on one side of the roof, then $\frac{1}{2}$ W will be the vertical strain upon the foot of the king-post arising from the

purlins on each side pressing down the braces. Taking the distance apart of the principals as 10 feet and the load per square foot of roofing as 66 lbs., or $\frac{1}{34}$ ton, we have $W = \frac{10\,L}{34} = \cdot 3\,L$ in tons where L is in feet, and the strain on the king-post $= \frac{W}{2} = \cdot 15\,L = \cdot 084\,S$. Taking the weight of tie-beam and ceiling at 1 cwt., or $\frac{1}{20}$ ton per foot length, the load on each tie-beam will be $\frac{S}{20}$, half of which, or $\cdot 025\,S$, is sustained by the king-post. Therefore, the total strain upon the king-post is $\cdot 11\,S$ in tons. We may safely strain a fir post with one-third of a ton per square inch of section, so that we can determine the scantling from the equation,

$$B \,.\, D = \cdot 33\,S = \tfrac{1}{3}\,S.$$

RULE. In a roof of which the height is one-fourth of the span, *one-third of the span in feet will be the area of section of the king-post in inches*, if the tie-beam carries a ceiling only; but where the tie-beam carries a floor as well, *the span in feet will be the area of section of the king-post in inches;* which divided by the breadth will give the thickness, or by the thickness will give the breadth.

QUEEN-POSTS AND SUSPENDING PIECES.

204.—Queen-posts and suspending pieces are strained in a similar manner to king-posts, but the load upon them is only proportional to that part of the length of the tie-beam suspended by each suspending piece or queen-post. In queen-posts the part suspended by each is generally one-third the span; and in such roofs as shown by *fig.* 2, *Plate* VII., the load on the purlin supported by the brace B is one-third of the weight on one side of the roof, and half this is the vertical strain at the foot of each queen. Proceeding as in the king-post roof, and putting W for the whole load on one side of each truss, we have—

$$\text{strain on each queen} = \frac{W}{6} = \cdot 05\,L = \cdot 028\,S;$$

$$\text{one-third the load on each tie-beam} = \frac{S}{60} = \cdot 017\,S.$$

Therefore the total strain on each queen is $\cdot 045\,S$, in tons, which being put equal to $\frac{1}{3}\,D \,.\, B$, gives—

$$B \,.\, D = \cdot 14\,S = \tfrac{1}{7}\,S, \text{ nearly.}$$

RULE. *One-seventh of the span in feet gives the area of section of the queen-post;* which area divided by the thickness will give the breadth; the tie-beam having a ceiling only to carry. If the tie-beam carries a floor we must take three-fifths of the span instead of one-seventh.

In the roofs shown on *Plate* IX., the queens Q have to sustain more than one-third the

load on the tie-beam, since the braces B assist in holding up the post D, which itself supports part of the tie-beam; in this case we may take B . D = $\frac{1}{6}$ S.

These rules give the scantling in the smallest part of the pieces; and in order to avoid the bad effects arising from the shrinking of the king- or queen-posts, the heads must be kept as small as possible, and the timber should be well seasoned. Hard oak makes the best, because it will be least compressed by the ends of the principal rafters.

205.—In modern roofs it is a common practice to substitute iron for the timber king- and queen-posts. The heads of the rafters are let into a cast-iron head, through which a wrought-iron bolt is passed which holds up the tie-beam, as shown by the examples on *Plates* XVI., XVIII., and XIX. (See Section IX.)

206.—The common method of forming the joint between the principal rafter and king-post is shown by *fig.* 2, *Plate* XLVIII.; but it is obvious that when the roof settles, unless it be provided for the change, the whole bearing will be on the upper angles of the joints, as at *a*, and these sharp angles will indent into the king-post, or became bruised, in proportion to the degree of settling, and of course increase it. And as all roofs will settle more or less, the carpenter will see how important it is to make the joints bear on the opposite corner when first fitted. To remedy this defect it has been proposed to make the joint in the form of a circular arc, in order that the pressure on every part may be equal, whatever degree of settling may take place. A joint of this kind is shown by *fig.* 5, and A and D show the parts separated. The centre for describing the arc should be in the middle of the depth of the rafter, and should be as near the end as possible, so as not to cut too much into the king-post. (See Section IX., Art. 316.)

By a method described in Section IX., Art. 317, *figs.* 6 and 7, *Plate* XLVI., the rafters abut against each other, and the tie-beam is suspended by pieces bolted on each side; which is perhaps the best practical method.

TIE-BEAMS.

207.—A tie-beam is affected by two strains: the one is a tensile strain in the direction of the length arising from the thrust of the principal rafters; the other is a cross strain arising from its own weight and that of the ceiling. In estimating the strength, the thrust of the rafters need not be considered, because the beam is always abundantly strong to resist this strain; and when a beam is strained in the direction of the length, it rather increases the strength to resist a cross strain. Therefore the pressure, or the weight supported by the tie-beam, will be proportional to the length of the longest part of it that is unsupported. But there are two cases: one where the weight is merely the weight of the ceiling; the other where there are rooms in the roof.

Case 1. To find the scantling of a tie-beam which has only to support a ceiling, the the length of the longest unsupported part being given.

Supposing the trusses to be 10 feet apart from middle to middle, the tie-beams may be considered as *binding-joists*, Art. 148, to the under side of which ceiling joists are attached, the scantling of which can be calculated by the formula given in Art. 148, only as the

distance apart is 10 feet instead of 6 feet, we must make the constant more than what it is in that rule; so that we may determine B or D from the equation,

$$B \cdot D^3 = L^3.$$

B and D being the breadth and depth in inches, and L the length of the longest unsupported part in feet; consequently we have the following—

RULE. *Divide the length in feet of the longest unsupported part of the tie-beam by the cube root of the breadth in inches;* the quotient will be the depth required in inches for fir beams.

Case 2. To find the scantling of a tie-beam which has rooms above as well as a ceiling below.

The same formula applies as in the first case, only as the load will be ten times as great we have the equation,

$$B \cdot D^3 = 10\ L^3,$$

from which we obtain the following—

RULE. *Divide the length in feet of the longest unsupported part of the tie-beam by the cube root of the breadth in inches;* the quotient multiplied by 2·2 will be the depth required in inches for fir beams.

208.—Tie-beams are often unnecessarily cut to pieces with mortises, where the king- or queen-posts join them; it is much better to make very short tenons to the lower end of these posts, and to support the beam by means of straps. The best method of cocking or cogging the tie-beam upon the wall-plate is shown by *fig.* 5, *Plate* XXVI., and also on *Plate* XXXI.

Sometimes blocks are placed under the ends of tie-beams, for the purpose of adding to the security of the roof if the ends of the tie-beams should decay. The roof of the Theatre d'Argentina, and that of the Basilica of St. Paul, have blocks of this kind. (See *Plate* XI.) The former roof of Covent Garden Theatre, and that of Drury Lane Theatre, were also formed in this manner; as well as several other modern roofs, examples of which are given in *Plates* XII., XIV., and XXX.

In respect to the use of these blocks as a security in case of decay, it can only be from affording a greater quantity of matter for the causes of decay to act upon, and is as likely to accelerate as to retard its progress. And by adding to the depth of timber at the points of support, the settlement from shrinkage will become considerable. Also, whether the blocks be firmly connected to the tie-beam or not, by raising the middle part of the tie-beam above the real points of support, a lateral pressure equivalent to that of a beam cambered in the same degree, will be exerted against the walls.

If the ends of the tie-beams be left with a perfectly free space round them, so that there would be nothing to retain any moisture in contact with them, there would be little to apprehend from decay. And, if a further security should be thought necessary, cast-iron plates, fixed to the sides of the tie-beams, might be used instead of wooden blocks, which would support the roof were the ends of the wooden beams to decay. Examples of this are seen in *Plates* VIII., XVI., XVIII., and XIX.

It is a common practice in framing roofs to force the tie-beam to a certain degree of camber, which appears to have been introduced under the idea that a cambered beam

partakes of the nature of an arch; this is one of the fallacies which it is the business of the mathematical theory of carpentry to dispel. It is obvious that, when a cambered beam settles, it has a tendency to thrust out the walls, instead of being a bond to tie them together. The Gothic builders sometimes laid naturally crooked timbers, with the round side upwards for tie-beams; but then their walls were capable of supporting considerable lateral pressure. In some of the tie-beams of Durham Cathedral this curvature is very considerable; but modern walls are constructed on different principles, and require all the connection a roof can be made to give them, instead of being sufficient to withstand the thrust of a cambered beam. Where there are ceiling joists it is easy to keep them a little higher in the middle of a ceiling, at the rate of about an inch in 20 feet, which prevents the settling from offending the eye of the beholder; and consequently accomplishes all that it is proposed to do by cambering the tie-beam.

PRINCIPAL RAFTERS.

209.—In estimating the strength of principal rafters, we may suppose them to be supported by struts, either at or very near all the points which the purlins rest upon. The pressure on a principal rafter is in the direction of its length, and is in proportion to the magnitude of the roof; but the effect of this pressure does not bear the same proportion to the weight when there is a king-post, as when there are queen-posts; therefore, the same constant number will not answer for both cases.

Case 1. *To find the scantling of the principal rafter when there is a king-post in the middle.*

It will be seen by referring to Art. 203 and *fig.* 6, *Plate* I., that the resolved part of the load on the purlin at C down the rafter is half that load divided by the *sine* of the angle of pitch, or $\frac{W}{4}$ divided by ·454, when that angle is 27°. We have also the compression arising from the load at the ridge, which will be $\frac{W}{4}$ divided by ·454. Consequently, the direct compression down the lower half of the rafter is 1·1 W, or ·185 S. The tensile strain on the king-post also produces a compression down the rafter of 1·1 × ·11 S (Art. 203), or ·121 S; and the total compression down the lower half of each rafter is therefore ·306 S. We may consider the lower half of the rafter as a pillar sustaining the above load, acting longitudinally; and putting l for the half length of the rafter, equal ·28 S, and d for the side of a square rafter, we have, by Art. 128,

$$\cdot 306\ S = \frac{d^4}{l^2}, \text{ or } d^4 = \cdot 024\ S^3,$$

where S is the span of the roof in feet.

RULE. *Multiply the cube of the span in feet by* ·024, and the *square-root* of the product will be the sectional area of the rafter in inches, for a king-post roof.

Case 2. *To find the scantling of a principal rafter when there are two queen-posts.*

In the *fig.* 2, *Plate* VII., there are two purlins on each side; the load at the lower one is $\frac{W}{3}$, and its compression down the rafter is $\frac{W}{6}$ divided by ·454, as shown above; W being the total load on one side of the roof. That on the upper purlin is $\frac{W}{2}$, and may be resolved in two directions, one parallel to the rafter P, and the other to the straining-beam S, as shown on the diagram, *fig.* 1, Art. 15, where C*c* represents the vertical load at the purlin, C*a* that in the straining-beam, C*b* the compression down the rafter, which is $\frac{W}{2}$ divided by the *sine* of the angle of pitch, or ·454. Consequently, the direct compression down the lower half of the rafter is 1·47 W, or ·246 S. To this we must add the component of the tensile strain on the queen-post, which by Art. 204 will be ·045 S divided by ·454, or ·099 S; giving as the total compression down the lower half of each rafter, ·345 S. And since $l = ·19$ S, the equation

$$·345\ S = \frac{d^4}{l^2} \text{ gives } d^4 = ·0125\ S^3.$$

where S is the span of the roof. Therefore, the rule for the scantling of a rafter in a queen-post roof is the same as that for a king-post roof, only the constant multiplier is ·0125 instead of ·024.

In *fig.* 10, *Plate* XLVII., is shown what is considered the best of the common methods of framing the end of the principal rafter into the tie-beam; and *fig.* 13 shows another method, with a circular abutment, which is considered by some to be preferable for large roofs: we must refer the reader to the Section on Joints (Section IX., Art. 315) for more particular information on this subject; and also to Art. 322 for the best mode of strapping.

STRAINING-BEAMS.

210.—A straining-beam is the horizontal piece between the heads of the queen-posts, and is marked S in the roof, *fig.* 2, *Plate* VII.

In order that this beam may be the strongest possible, its depth should be to its thickness as 10 is to 7.

The strain on this beam is entirely a compressive one, if we except the small transverse strain arising from its own weight; consequently, its strength can be determined by the rules for pillars, as in the case of rafters.

Supposing W to be the load on one side of the roof, and $\frac{1}{2}$ W, or ·084 S, to be supported on the top of the queen-post, this load may be resolved in the directions of the rafter and straining-beam, as shown in *fig.* 1, Art. 15, C*a* representing the component in the latter. We have also the resolved part of the tensile strain on the queen-post, which by Art. 204 is ·045 S. Therefore, the compression C*a* in the straining-beam will be ·129 S multiplied by the *cotangent* of the angle of pitch, and will be ·2532 S when this angle is 27°. Putting l for the length of the beam, which in this case is $\frac{1}{3}$ S, the equation for its strength as a pillar is

$$d^4 = l^2 \times ·2532\ S = ·028\ S^3.$$

RULE. *Multiply the cube of the span of the roof in feet by* ·028, and the *square-root* of the product will be the sectional area of the straining-beam in inches.

The mode of jointing the ends of the straining-beam into the head of the queen-post is shown on *Plate* XLVIII., *figs.* 4 and 5, and described in Section IX., Art. 316.

In the example given on *Plate* IX., *fig.* 2, the straining-beam is held up in the middle by a king-post, and consequently its length as a pillar is shortened by one-half. In this case the value of l is $\frac{1}{6}$ S, therefore we have

$$d^4 = \cdot 007\ S^3.$$

STRUTS AND BRACES.

211.—That part of a roof which is supported by a strut or brace is easily ascertained from the design, but the effect of the load must depend on the position of the brace; when it is square from the back of the rafter the strain upon it will be the least; and when it has the same inclination as the roof, the same strain will be thrown on the lower part of the principal rafter as is borne by the strut. But as the degree of obliqueness does not vary much we shall not attempt to include its effect in the rule for the scantling. These beams are marked B on *Plates* VII., IX., and X. The compression on a strut is shown by the length C*b*, *fig.* 6, *Plate* I., where C*c* represents the load on the purlin at C. Consequently, the compression down the strut is half the load at C divided by the *sine* of the angle C*ba*, which is generally equal to the angle of pitch. Therefore, in the case of the king-post roof, *fig.* 1, *Plate* VII., we have the equation

$$d^4 = \cdot 0073\ S^3.$$

In the case of the queen-post roof on *Plate* VII. the scantling of the struts can be found from

$$d^4 = \cdot 0023\ S^3.$$

RULE. *Multiply the cube of the span in feet by* ·0073 in the case of a king-post roof, and *by* ·0023 in that of a queen-post roof, and the *square-root* of the product is the sectional area of the strut in inches.

If a piece intended for a brace, a principal rafter, or a straining-beam, be curved, the convex side should be placed upwards.

212.—We have now laid down rules for the principal parts of a truss; but in so doing we have not taken into the account the different weights of different kinds of roofing, nor the different degrees of inclination, lest the rules should become too complicated: indeed many will probably suppose them too much so already; but the numerous tables of scantlings at the end of the volume will be found useful to those who are not ready at calculation; and to others the assistance of a table of squares and cubes, or a table of logarithms will render all the rules extremely easy. It only remains now to give the rules for purlins and common rafters.

PURLINS.

213.—The stress upon purlins is proportional to the distance they are apart; and the weight being uniformly diffused, the stiffness is reciprocally as the cube of the length.

Using the formula for the strength of joists, Art. 137,

$$B \cdot D^3 = \tfrac{5}{8} \times \cdot 01 \times w \cdot l^3,$$

we have w the weight on one foot length as the actual load multiplied by the *cosine* of the angle of pitch, since the purlin is fixed at right angles to the slope of the rafter. If we put x for the distance apart of the purlins, then $w = 66x \times \cdot 89$, when the angle is 27°. Therefore we have

$$B \cdot D^3 = \cdot 367 \cdot x \cdot l^3.$$

In the king-post, *Plate* VII., $x = \cdot 28$ S, where S is span in feet; and in the queen-post roof on the same plate, $x = \cdot 19$ S. From this formula the breadth can be found when the depth is given, or the depth when the breadth is given; when we know either the distance apart of the purlins, or the span of the roof; if $l = 10$ feet, then

$$B \cdot D^3 = 367\, x.$$

Table XXXVI., at the end of this Section, gives the scantling of purlins for different values of x and l.

Purlins should always be notched upon the principal rafters, and should be put on in as long lengths as they can be conveniently got, as the strength is nearly doubled by this means. The old method of framing the purlins into the principal rafters not only renders the purlins weaker, but also wounds the principal rafter, and consequently renders it necessary to make the rafters stronger.

There is no part of a roof so liable to fail as the purlins; indeed there are few cases where they have not sunk considerably; and in some instances so much as to deform the external appearance of the roof. Weak purlins might be much strengthened by bracing them: a practice which was once very common among the builders in this country.

COMMON RAFTERS.

214.—Common rafters are uniformly loaded, and the breadth need not be more than from 2 inches to $2\frac{1}{2}$ inches. The depth for Welsh slate may be found by the same formula as was used for purlins, only in this case we put $x = 1$ foot.

$$D^3 = \cdot 367 \frac{l^3}{B}.$$

In the king-post roof, *Plate* VII., $l = \cdot 28$ S, and in the queen-post roof, $l = \cdot 19$ S.

The scantling of rafters for different values of l are given in Table XXXVII., at the end of this Section.

Foreign fir of straight grain makes the best common rafters and purlins, because it is not so subject to warp and twist with the heat of roofs in summer as oak; much, however, depends on the quality of the timber; oak from old trees often stands very well.

ON HIPPED ROOFS.

215.—When a roof is *hipped* at one end, the *hip-rafter* has to be bevelled on the top edge to receive the covering; the purlins have to be bevelled at the ends where they abut against the hip-rafter; and the jack-rafters have to be bevelled at the ends which are fixed to the hip-rafter. The following geometrical construction is taken from Nicholson's *Carpenter's New Guide*,* to which the reader is referred for further information on the geometry of roof framing.

In *Plate* XXXI., let $a\,b$ be the end of a rectangular roof, $a\,e$ and $b\,f$ being a part of each side on plan, and made each equal to half $a\,b$; draw $e\,f$ and bisect it in c. Draw $c\,d$ perpendicular to $e\,f$ and equal to the *height of the roof*. Draw $d\,e$, $d\,f$, which are *the lengths of the common rafters*; join $a\,c$ and $b\,c$, and produce $b\,c$ to g, making $c\,g$ equal to $c\,d$; draw $a\,g$, which is the *length of each hip*. The triangle $e\,d\,f$ represents the section of the roof, and $e\,a\,b\,f$ its plan.

Draw any line $x\,y$ perpendicular to the *seat* $a\,c$ of a hip at D, cutting $a\,e$ and $a\,b$ at x and y, and $a\,c$ at z. With z as a centre describe a circle touching $a\,g$, and cutting $a\,c$ at w; join $w\,x$ and $w\,y$, and the angle $y\,w\,x$ is the inclination of the planes which form the hip angle, generally termed the backing of the hip.

To find the Bevels of a Purlin against the Hip-Rafter.

When the purlin lies level, or has two sides parallel to the horizon, the square at B, and the bevel at C, will show how to draw the end of the purlin. But the following method is universal in all positions of the purlin.

Let the purlin be in any place of the rafter, as at I, and at right angles to the rafter. From h as a centre, and with any radius, describe a circle; draw $p\,n$ and $q\,l$ parallel to $f\,b$, and touching the circle in p and q; and at the points s and r, where the circle and two sides of the purlin intersect, draw two parallel lines to the former, to cut the diagonal $b\,c$ in m and k; draw $m\,n$ and $k\,l$ perpendicular to $s\,m$ and $r\,k$; draw $n\,i$ and $l\,i$; then G is the *down bevel*, and F the *side bevel* of a purlin. These two bevels, when applied to the end of the purlin, and when cut by them, will exactly fit the side of the hip-rafter.

* Crosby Lockwood & Co.

To find the Bevels of a Jack-Rafter against the Hip.

By turning the stock of the side bevel of the purlin, at F, from *a* round to the line *Zi* we get the *side bevel* of the *jack-rafter*. And the bevel at A, that is, the top of a common rafter, is the *down bevel* of the *jack-rafter*.

The lines *e d*, *d f*, may represent either the outside or inside of the rafter, as the lines *e a*, *a b*, *b f*, may represent the outside or inside lines of the plan; but it is much the best way to draw these lines as *inside* lines, as they represent the building in the clear; and the depths of the timbers should be added externally afterwards.

TABLE XXVIII.—*Scantlings of Timbers of different Spans from* 20 *to* 30 *feet, for the Roof shown in* fig. 1, Plate VII. (See Art. 167.)

Span.	Tie-beam A.	King-post K.	Principal rafters P.	Braces B.	Purlins C.	Small rafters *r*.
feet.	inches.	inches.	inches.	inches.	inches.	inches.
20	7 × 4	3 × 3	4 × 4	$3\frac{1}{2}$ × 2	8 × 4	$3\frac{1}{2}$ × 2
22	7 4	4 3	5 4	$3\frac{3}{4}$ $2\frac{1}{4}$	8 $4\frac{1}{2}$	$3\frac{3}{4}$ 2
24	8 4	4 $3\frac{1}{2}$	5 $4\frac{1}{2}$	4 $2\frac{1}{2}$	8 5	4 2
26	8 5	5 4	5 5	$4\frac{1}{4}$ $2\frac{1}{2}$	$8\frac{1}{2}$ 5	$4\frac{1}{4}$ 2
28	$8\frac{1}{2}$ 5	5 4	6 5	$4\frac{1}{2}$ $2\frac{3}{4}$	$8\frac{3}{4}$ 5	$4\frac{1}{2}$ 2
30	9 5	5 $4\frac{1}{2}$	6 5	$4\frac{3}{4}$ 3	9 5	$4\frac{3}{4}$ 2

In this table the trusses are supposed to be not more than 10 feet apart, the pitch of the roof about 27 degrees, the covering slate, and the timber yellow fir. The timbers are marked with the letters A, K, P, B, C, and *r*, in the engraving.

TABLE XXIX.—*Scantlings for Roofs from* 30 *to* 46 *feet Span, to Design* fig. 2, Plate VII., *Trusses* 10 *feet apart.* (See Art. 168.)

Span.	Tie-beam A.	Queen-posts Q.	Principal rafters P.	Straining-beam S	Braces B.	Purlins C.	Small rafters *r*.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
32	7 × $4\frac{1}{2}$	4 × 2	5 × $4\frac{1}{2}$	7 × $4\frac{1}{2}$	$3\frac{3}{4}$ × $2\frac{1}{4}$	8 × 4	$3\frac{1}{2}$ × 2
34	7 5	5 2	5 5	7 5	4 $2\frac{1}{2}$	8 5	$3\frac{3}{4}$ 2
36	$7\frac{1}{2}$ 5	5 2	$5\frac{1}{2}$ 5	$7\frac{1}{2}$ 5	$4\frac{1}{4}$ $2\frac{1}{2}$	8 5	4 2
38	8 5	5 $2\frac{1}{2}$	$5\frac{1}{2}$ 5	8 5	$4\frac{1}{2}$ $2\frac{1}{2}$	$8\frac{1}{2}$ 5	4 2
40	8 5	5 3	6 5	$8\frac{1}{2}$ 5	$4\frac{1}{2}$ $2\frac{1}{2}$	$8\frac{3}{4}$ 5	$4\frac{1}{4}$ 2
42	$8\frac{1}{2}$ 5	5 3	$6\frac{1}{2}$ 5	9 5	$4\frac{1}{2}$ $2\frac{3}{4}$	$8\frac{3}{4}$ 5	$4\frac{1}{2}$ 2
44	9 $5\frac{1}{2}$	5 3	7 $5\frac{1}{2}$	9 $5\frac{1}{2}$	$4\frac{1}{2}$ 3	9 5	$4\frac{3}{4}$ 2
46	$9\frac{1}{2}$ $5\frac{1}{2}$	5 $3\frac{1}{2}$	$7\frac{1}{2}$ $5\frac{1}{2}$	10 $5\frac{1}{2}$	$4\frac{3}{4}$ 3	9 5	5 2

Pitch of the roof about 27 degrees, or height equal one-fourth of span, covering slate, and timber yellow fir. The letters refer to the engraving, as in the table above.

The scantlings in these tables are calculated by the rules in Arts. 203 to 214. The scantlings are the smallest that ought to be used for good Riga or Memel timber; of course soft and inferior kinds of timber will require them to be larger.

TABLE XXX.—*Scantlings for Roofs of from* 48 *to* 60 *feet Span, to Design* fig. 1, Plate IX.; *Trusses* 10 *feet apart.* (See Art. 169.)

Span.	Tie-beam A.	Queen-posts Q.	Posts D.	Principal rafters P.	Straining-beam S.	Braces B.	Purlins C.	Small rafters r.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
48	9 × 6	3 × 5	5 × $2\frac{1}{4}$	6 × 6	8 × 5	$4\frac{1}{2}$ × $2\frac{3}{4}$	$8\frac{1}{2}$ × 5	4 × 2
50	10 6	4 5	5 $2\frac{1}{2}$	7 6	9 5	$4\frac{1}{2}$ $2\frac{3}{4}$	$8\frac{3}{4}$ 5	$4\frac{1}{4}$ 2
52	10 6	4 6	6 $2\frac{1}{4}$	7 6	8 6	$4\frac{3}{4}$ $2\frac{3}{4}$	$8\frac{3}{4}$ $5\frac{1}{4}$	$4\frac{1}{4}$ 2
54	10 6	4 6	6 $2\frac{1}{4}$	$7\frac{1}{2}$ 6	9 6	$4\frac{3}{4}$ $2\frac{3}{4}$	$8\frac{3}{4}$ $5\frac{1}{4}$	$4\frac{1}{2}$ 2
56	$10\frac{1}{2}$ 6	$4\frac{1}{2}$ 6	6 $2\frac{1}{2}$	8 6	9 6	5 $2\frac{3}{4}$	$8\frac{3}{4}$ $5\frac{1}{4}$	$4\frac{1}{2}$ 2
58	11 6	5 6	6 $2\frac{3}{4}$	8 6	$9\frac{1}{2}$ 6	5 $2\frac{3}{4}$	9 $5\frac{1}{4}$	$4\frac{3}{4}$ 2
60	11 7	5 7	7 3	8 7	10 7	5 3	9 $5\frac{1}{2}$	$4\frac{3}{4}$ 2

TABLE XXXI.—*Scantlings for Roofs from* 65 *to* 90 *feet Span, to Design* fig. 2, Plate IX.; *Trusses* 10 *feet apart.* (See Art. 170.)

Span.	Tie-beam A.	Queen-posts Q.	Posts D.D.	Principal rafters P.	Straining-beam S.	King-post K.	Braces B.	Purlins C.	Small rafters r.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
65	12 × 7	4 × 7	7 × 3	8 × 7	10 × 7	5 × 3	5 × $3\frac{1}{2}$	$8\frac{1}{4}$ × 5	4 × 2
70	$12\frac{1}{2}$ 7	5 7	7 3	9 7	$10\frac{1}{2}$ 7	5 $3\frac{1}{2}$	5 4	$8\frac{1}{2}$ 5	$4\frac{1}{4}$ 2
75	$12\frac{1}{2}$ 8	5 8	8 3	9 8	11 8	5 4	5 $4\frac{1}{2}$	$8\frac{3}{4}$ 5	$4\frac{1}{2}$ 2
80	$13\frac{1}{2}$ 8	$5\frac{1}{2}$ 8	8 4	10 8	12 8	6 4	6 $3\frac{1}{2}$	$8\frac{3}{4}$ $5\frac{1}{4}$	$4\frac{1}{2}$ 2
85	$13\frac{1}{2}$ 9	6 9	9 4	10 9	12 9	6 $4\frac{1}{2}$	6 4	9 $5\frac{1}{4}$	$4\frac{3}{4}$ 2
90	14 9	7 9	9 $4\frac{1}{2}$	11 9	13 9	6 $4\frac{1}{2}$	6 4	9 $5\frac{1}{2}$	5 2

In these tables the pitch of the roof is supposed to be about 27 degrees, the covering slate and the timber to be good Riga or Memel fir. Inferior timber will require to be of larger dimensions, but the addition of one-fourth of an inch to each dimension will be sufficient for any difference in quality, except it be knotty timber. The letters refer to the parts on the engravings.

TABLE XXXII.—*Scantlings for Roofs from* 55 *to* 65 *feet Span, to Design* fig. 1, Plate X.; *Trusses* 10 *feet apart.* (See Art. 171.)

Span.	Tie-beam A.	Queen-posts Q.	Principal rafters P.	Straining-beam S.	Posts D.	Braces B.
feet.	inches.	inches.	inches.	inches.	inches.	inches.
55	10 × 5	4 × 5	8 × 5	10 × 5	5 × 4	5 × 4
60	10 × 6	4 × 6	8 × 6	10 × 6	6 × 4	6 × 4
65	11 × 7	5 × 7	9 × 7	11 × 7	7 × 5	7 × 4

In roofs of this design, and between 55 and 65 feet span, the purlins may be 9 inches by 5 inches, and common rafters 5 inches by 2 inches.

TABLE XXXIII.—*Scantlings for Roofs from* 70 *to* 85 *feet Span, to Design* fig. 2, Plate X.; *Trusses* 10 *feet apart.* (See Art. 172.)

Span.	Tie-beam A.	Queen-posts Q.	Principal rafters P.	Straining-beam S.	
feet.	inches.	inches.	inches.	inches.	
70	11 × 9	9 × 6	13 × 9	12 × 9	Scantlings of the upper parts may be got from Table XXVIII.
75	12 × 9	9 × 7	13½ × 9	12½ × 9	
80	12 × 10	10 × 7	14 × 10	13 × 10	
85	13 × 10	8 × 10	14½ × 10	13½ × 10	

TABLE XXXIV.—*Scantlings for Roofs from* 20 *to* 32 *feet Span, to Design* fig. 6, Plate XI.; *Trusses* 10 *feet apart.* (See Art. 183.)

Span.	Tie-beam.	Curved rib.	Suspending pieces.		Purlins.	Common rafters.
			No. of pairs.	Scantlings of each piece.		
feet.	inches.	inches.		inches.	inches.	inches.
20	8 × 4	4 × 4	3	4 × 2	8 × 5	3½ × 2
24	8 × 4	4¾ × 4	3	4 × 2	8 × 5	4 × 2
28	8 × 5	5¼ × 5	3	4 × 2¼	8½ × 5	4½ × 2
30	8½ × 5	6 × 5	3	4 × 2¼	8½ × 5	4¾ × 2
32	9 × 5½	6 × 5½	3	4 × 2½	8½ × 5	5 × 2

The pitch, &c., the same as the preceding tables.

TABLE XXXV.—*Scantlings for Roofs from* 35 *to* 100 *feet Span, to Design* fig. 3, Plate XI.; *Trusses* 10 *feet apart.* (See Art. 182.)

Span.	Tie-beam.	Curved rib.	Suspending pieces.		
			No of pairs.	Scantling of each piece.	
feet.	inches.	inches.		inches.	
35	11 × 6	6 × 6	4	4 × $2\frac{1}{2}$	Purlins 9 × 5 inches.
40	11 6	7 6	4	4 $2\frac{3}{4}$	
45	11 $6\frac{1}{2}$	8 $6\frac{1}{2}$	5	4 $2\frac{3}{4}$	
50	11 7	9 7	5	4 3	
55	11 7	10 7	6	4 3	
60	11 8	10 8	6	4 $3\frac{1}{4}$	
65	11 9	10 9	7	4 $3\frac{1}{4}$	
70	11 $9\frac{1}{2}$	11 $9\frac{1}{2}$	7	$4\frac{1}{2}$ $3\frac{1}{4}$	Small rafters 5 × 2 inches.
75	11 10	11 10	8	$4\frac{1}{2}$ $3\frac{1}{4}$	
80	12 10	12 10	9	$4\frac{1}{2}$ $3\frac{1}{4}$	
85	12 11	$12\frac{1}{2}$ 11	9	$4\frac{1}{2}$ $3\frac{1}{2}$	
90	12 11	14 11	10	5 $3\frac{1}{4}$	
95	12 12	14 12	11	5 $3\frac{1}{2}$	
100	12 12	15 12	11	5 4	

The pitch is supposed to be about 27 degrees, the covering slate, and the timber good Riga or Memel fir.

TABLE XXXVI.—*Scantlings of Purlins, of Yellow Fir, of different Bearings, from* 6 *to* 14 *feet; distances apart,* 6 *feet,* 7 *feet,* 8 *feet, and* 9 *feet.* (See Art. 213.)

Length of bearing in feet.	6 feet apart.		7 feet apart.		8 feet apart.		9 feet apart.		Length of bearing in feet.
	Depth in inches.	Breadth in inches.	Depth in inches.	Breadth in inches.	Depth in inches.	Breadth in inches.	Depth in inches.	Breadth in inches.	
6	6	$3\frac{1}{2}$	6	$3\frac{3}{4}$	$5\frac{1}{2}$	4	$5\frac{1}{2}$	$4\frac{1}{4}$	6
7	6	4	6	$4\frac{1}{4}$	6	$4\frac{1}{2}$	6	$4\frac{1}{2}$	7
8	6	$4\frac{1}{2}$	6	$4\frac{3}{4}$	7	$4\frac{3}{4}$	$6\frac{1}{2}$	5	8
9	7	5	$6\frac{1}{2}$	$5\frac{1}{4}$	$7\frac{1}{2}$	$5\frac{1}{4}$	7	$5\frac{1}{2}$	9
10	$7\frac{1}{2}$	$5\frac{1}{4}$	$7\frac{1}{2}$	$5\frac{1}{2}$	8	$5\frac{3}{4}$	8	$5\frac{3}{4}$	10
11	8	$5\frac{3}{4}$	8	$5\frac{3}{4}$	$8\frac{1}{2}$	6	$8\frac{1}{2}$	$6\frac{1}{4}$	11
12	$8\frac{1}{2}$	6	$8\frac{1}{2}$	$6\frac{1}{4}$	9	$6\frac{1}{2}$	9	$6\frac{3}{4}$	12
13	9	$6\frac{1}{2}$	9	$6\frac{3}{4}$	$9\frac{1}{2}$	7	$9\frac{1}{2}$	$7\frac{1}{4}$	13
14	$9\frac{1}{4}$	$6\frac{3}{4}$	$9\frac{1}{2}$	7	10	$7\frac{1}{4}$	$10\frac{1}{2}$	$7\frac{1}{2}$	14

Purlins may often be found apparently strong enough of less scantlings than these, but in such cases the common rafters will be found to be stronger than is necessary. But it is most economical to make the rafters no stronger than is necessary to carry the load between the purlins, and the purlins sufficiently strong to carry the rafters.

TABLE XXXVII.—*Scantlings of Common Rafters for Roofs, for different Bearings, from* 5 *to* 20 *feet; distance apart* 12 *inches.* (See Art. 214.)

Length of bearing in feet.	Breadth $1\frac{3}{4}$ inches.	Breadth 2 inches.	Breadth $2\frac{1}{4}$ inches.	Breadth $2\frac{1}{2}$ inches.	Breadth $2\frac{3}{4}$ inches.	Breadth 3 inches.	Breadth $3\frac{1}{2}$ inches.	Breadth 4 inches.	Breadth $4\frac{1}{2}$ inches.	Length of bearing in feet.
	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	
5	3	$2\frac{7}{8}$	$2\frac{3}{4}$	...	...	...	...	...	...	5
6	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$3\frac{1}{2}$	3	...	...	...	...	6
7	$4\frac{1}{8}$	4	$3\frac{3}{4}$	$3\frac{5}{8}$	$3\frac{1}{2}$	...	...	...	...	7
8	$4\frac{3}{4}$	$4\frac{5}{8}$	$4\frac{3}{8}$	$4\frac{1}{4}$	$4\frac{1}{8}$	4	$3\frac{3}{4}$	...	...	8
9	$5\frac{1}{4}$	$5\frac{3}{8}$	5	$4\frac{3}{4}$	$4\frac{5}{8}$	$4\frac{1}{2}$	$4\frac{1}{4}$	...	...	9
10	6	$5\frac{3}{4}$	$5\frac{1}{2}$	$5\frac{3}{8}$	$5\frac{1}{8}$	5	$4\frac{3}{4}$	$4\frac{1}{2}$	...	10
11	$6\frac{1}{2}$	$6\frac{1}{4}$	6	$5\frac{3}{4}$	$5\frac{5}{8}$	$5\frac{1}{2}$	$5\frac{1}{4}$	5	$4\frac{3}{4}$	11
12	7	$6\frac{3}{4}$	$6\frac{1}{2}$	$6\frac{3}{8}$	$6\frac{1}{4}$	6	$5\frac{3}{4}$	$5\frac{1}{2}$	$5\frac{1}{4}$	12
13	$7\frac{3}{4}$	$7\frac{1}{2}$	$7\frac{1}{4}$	7	$6\frac{3}{4}$	$6\frac{1}{2}$	$6\frac{1}{4}$	$5\frac{3}{4}$	$5\frac{5}{8}$	13
14	$8\frac{1}{4}$	8	$7\frac{3}{4}$	$7\frac{1}{2}$	$7\frac{1}{4}$	7	$6\frac{3}{4}$	$6\frac{1}{4}$	$6\frac{1}{8}$	14
15	$8\frac{3}{4}$	$8\frac{1}{2}$	$8\frac{1}{4}$	8	$7\frac{3}{4}$	$7\frac{1}{2}$	$7\frac{1}{4}$	$6\frac{3}{4}$	$6\frac{5}{8}$	15
16	$9\frac{1}{2}$	$9\frac{1}{4}$	$8\frac{3}{4}$	$8\frac{1}{2}$	$8\frac{1}{4}$	8	$7\frac{3}{4}$	$7\frac{1}{4}$	7	16
17	10	$9\frac{3}{4}$	$9\frac{1}{2}$	9	$8\frac{3}{4}$	$8\frac{1}{2}$	$8\frac{1}{4}$	8	$7\frac{1}{2}$	17
18	$10\frac{1}{2}$	$10\frac{1}{4}$	10	$9\frac{1}{2}$	$9\frac{1}{4}$	9	$8\frac{3}{4}$	$8\frac{1}{2}$	8	18
19	11	$10\frac{7}{8}$	$10\frac{1}{2}$	10	$9\frac{3}{4}$	$9\frac{1}{2}$	9	$8\frac{3}{4}$	$8\frac{1}{4}$	19
20	$11\frac{3}{4}$	$11\frac{1}{2}$	11	$10\frac{1}{2}$	$10\frac{1}{4}$	10	$9\frac{1}{2}$	9	$8\frac{3}{4}$	20

Roofs that are covered with plain tiles, or stone slate, will require rafters one-third stronger than is necessary for blue slate. The table will answer for either, for it is calculated for blue slate; and if to the breadth found at the head of a column, half of that breadth be added, it will give the breadth required for stone slate or plain tiles. Thus for a rafter of 7 feet bearing, 4 inches by 2 inches is sufficient for blue slate; and therefore 4 inches by 3 inches is the scantling for stone slate, or plain tiles.

Purlins also require the same addition to their breadths when the covering is of plain tiles, or stone slates.

SECTION V.

ON THE CONSTRUCTION OF DOMES AND SPIRES.

DOMES OR CUPOLAS.

216.—A DOME or cupola is a roof, the base of which is a circle, an ellipsis, or a polygon; and its vertical section a curve line, concave towards the interior. Hence, domes are called circular, elliptical, or polygonal, according to the figure of the base.

The most usual form for a dome is the spherical, in which case its plan is a circle, the section a segment of a circle.

The top of a large dome is often finished with a *lantern*, which is supported by the framing of the dome.

The interior and exterior forms of a dome are not often alike, and in the space between, a staircase to the lantern is generally made. According to the space left between the external and internal domes, the framing must be designed. Sometimes the framing may be trussed with ties across the opening; but often the interior dome rises so high that ties cannot be inserted: in the latter case, the observations made on the equilibrium of domes in Section I. (Arts. 62—66) should be attended to.

Accordingly, the construction of domes may be divided into two cases, viz., domes with horizontal ties, and those not having such ties:

ON THE CONSTRUCTION OF DOMES WHICH ADMIT OF HORIZONTAL TIES.

217.—A truss for a dome where horizontal ties can be inserted is shown by *fig.* 1, *Plate* XXXII. In this figure AA is the tie; BB posts, which may be continued to form the lantern; C, C are continued curbs in two thicknesses, with the joints crossed and bolted together; DD a curved rib to support the rafters. This design is calculated for a span of about 60 feet, and may be extended to 120 feet.

Two principal trusses may be placed across the opening, parallel to each other, and at a distance equal to the diameter of the lantern apart, as AB, CD, *fig.* 2; with a sufficient number of half-trusses to reduce the bearing of the rafters to a convenient length.

Or, the two principal trusses may cross each other at right angles in the centre of the dome, the one being placed so much higher than the other as to prevent the ties interfering.

This disposition is represented in *fig.* 3; and is the same that is adopted for the Dôme des Invalides, at Paris, of which the external diameter is nearly 90 English feet.

As the dimensions of the parts must depend chiefly on the weight of the lantern, it is scarcely possible to fix upon any, unless some particular design had been described, which would not have been satisfactory; besides being likely to mislead, as there are few cases that are similar. The dimensions of the timbers may, however, be easily ascertained to any particular design, from the rules and principles laid down in Sections I. and II.

218.—In the construction of the outer dome of St. Paul's Cathedral, London, Sir C. Wren did not rely upon timber alone, but erected a conical dome of brick, 18 inches thick, outside the inner dome, and to this he attached the horizontal ties or braces which held the ribs of the outer dome in their places. A half-section of this dome is shown on *fig.* 23, page 144. Girdles of stone were built into the brick cone at the points A, B, C, D, and E, from which corbels projected to carry the ends of the tie-beams, iron cramps being bedded with lead in the corbels and bolted to the beams. Iron chains were also built into the cone at the points A, B, E, and F, to prevent any lateral thrust from the cone. The outer surface of the dome is formed with curved ribs, into which are halved horizontal purlins, 14 inches from centre to centre, and on this the boarding and lead covering are laid. The tie-beams are tied with iron straps to the ribs, and are stiffened with vertical posts and diagonal bracing.

ON THE CONSTRUCTION OF DOMES WITHOUT HORIZONTAL TIES.

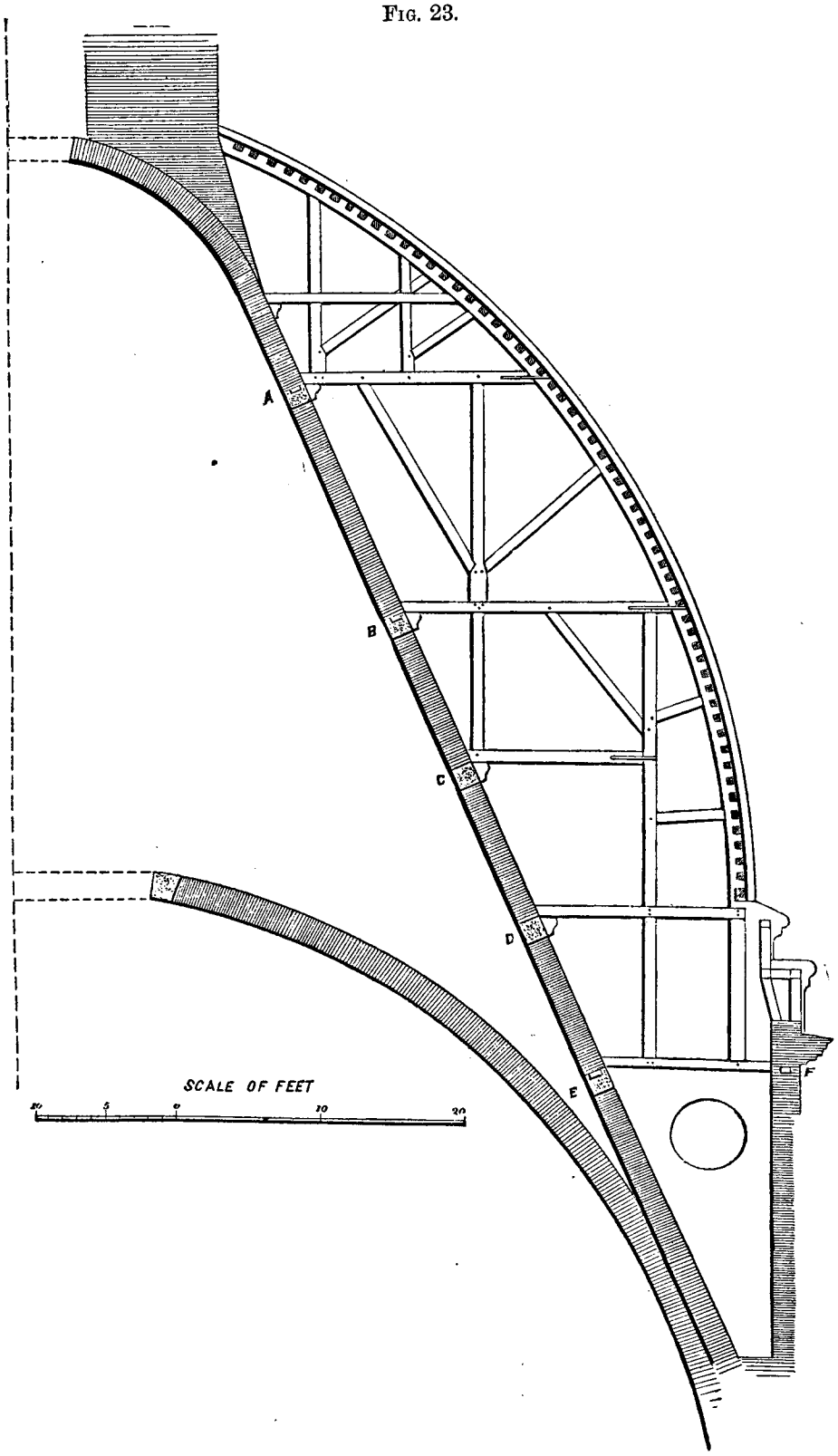
219.—The construction of domes without horizontal cross ties is not difficult, when there is a sufficient tie round the base. The most simple method, and one which is particularly useful in small domes, is to place a series of curved ribs so that the lower ends of those ribs stand upon the curb at the base, and the upper ends meet at the top, with diagonal struts between the ribs.

When the pieces are so long and so much curved that they cannot be cut out of timber without being cut across the grain so much as to weaken them, they should be put together in thicknesses, with the joints crossed, and well nailed together: or in very large domes, they should be bolted or keyed together. The manner of forming these ribs has been already described, as applied to roofs. (See Section IV., Art. 182.) This method of making curved ribs in thicknesses has been used in the construction of centres for arches from the earliest period of arch building; and it was first applied to the construction of domes by Philibert de Lorme, who gives the following scantlings for different sized domes:—

For domes of	24	feet diameter	8	inches by	1 inch.
„	36	„	10	„	$1\frac{1}{2}$ inches.
„	60	„	13	„	2 „
„	90	„	13	„	$2\frac{1}{2}$ „
„	108	„	13	„	3 „

These ribs are formed of two thicknesses, of the scantlings given above, and are placed about 2 feet apart at the base. The rafters are notched upon them for receiving the

FIG. 23.



boarding, and also horizontal ribs are notched on the inside, which gives a great degree of stiffness to the whole. *Fig.* 4 is a section of a dome constructed in this manner; and *fig.* 5 a projection of a part of the dome, with the rafters and inside ribs.

If the dome be of considerable magnitude, the curve of equilibrium should pass through the middle of the depth of the ribs, particularly if a heavy lantern rests upon them. The curve in either case will be found by means of Art. 68 or 69, Section I. Otherwise the curve must fall within the curve of equilibrium, and struts must be placed between the ribs, to prevent them bending in. Or, if it be necessary for the external appearance of the dome that the curvature of the ribs should be without the curve of equilibrium, then an iron hoop may be put round about one-third of the height to prevent the dome bursting outwards. This latter method was adopted in the external dome of the Church de la Salute at Venice, the outside dimensions of which are 80 feet diameter, 40·5 feet high, and the lantern 39·5 feet high; but the lantern is supported by a brick dome, which is considerably below the wooden one. The ribs of this dome are ninety-six in number, and each rib is in four thicknesses; the four together make 5·5 inches, so that each rib is 8·5 inches by 5·5 inches. The iron hoop is 4·5 inches wide, and half-an-inch in thickness, and is placed at one-third of the height of the dome.

When a dome is intended to support a heavy lantern, it may require the principal ribs to be stronger than can be obtained out of a piece of timber; but the framing may always be made sufficiently strong by using two ribs, with braces between, and tied together by radial pieces across from rib to rib. A truss of this form is shown by *fig.* 6, which would sustain a very heavy lantern, if the curve of equilibrium were to pass in the middle between the ribs, as the dotted line does in the figure. The proper form for the curve will be found by the equations in Art. 69, Section I.

Where a light dome is wanted, without occupying much space, the ribs may be placed so near to each other that the boards may be fixed to them without rafters, or short struts may be put between the ribs, as shown by *fig.* 7.

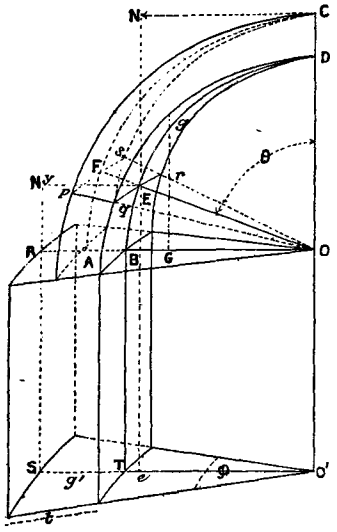
In a splendid collection of specimens of carpentry in the *Recueil de Charpente*, by M. Krafft, there are methods of finding the position of the principal timbers in domes and roofs shown, which were proposed by M. Stierme, a carpenter of Wurtemberg. Krafft's work contains no explanation of these methods, and they appear to be destitute of anything like sound principle, particularly as applied to domes, and are only noticed as a caution to the young student.

220.—The thrust which domes without a horizontal tie produce upon the supporting walls can be determined by mathematical analysis, and the requisite thickness of the walls to insure stability in the structure can be calculated therefrom. A method of doing this in the case of domes of stone or brick has been given in a paper by E. Wyndham Tarn, which was read before the Royal Society (see the *Proceedings of the Royal Society*, No. 85, 1866), and as the same method applies to domes of timber or any other material, we shall give an outline of the method of investigation.

Consider the dome to be made up of a large amount of arched ribs, or "lunes," one of which is shown in *fig.* 24, the base of which rests on the top of a circular wall, or "drum," and subtends a small angle (ϕ) at the centre, diminishing upwards in thickness to nothing; each rib having the form of a wedge cut out of the spherical shell by two planes intersecting

in a vertical line through the centre, and making the small angle ϕ with each other. Consider also that the two wedges thus formed on opposite sides of the dome, thrust against each other at the vertex, as in the case of an ordinary semi-circular arch, and by this means keep each other in equilibrium. Of course no arch of this form, if built alone, could stand for a moment, as it would give way laterally; but in the dome this is prevented by the pressure of the parts on each side of the rib under consideration.

FIG. 24.



This arch will have a tendency to fall in at the crown CD, and open outwards at the haunches EF, causing the joint CD to open at D, and that at EF to open at F. We may therefore suppose that the thrust N of the corresponding rib on the opposite side acts at C.

We shall now find the effect of the force N upon a given joint EF. Let P be the weight and V the volume of the portion of rib above EF; x the perpendicular distance from E of a vertical from the centre of gravity of P; y the vertical distance of CN from E. Then the moments of these forces about E are Px and Ny; and in order that there may be equilibrium, we must have N equal to the greatest value of $P.\frac{x}{y}$. We have therefore to express $P\frac{x}{y}$ in terms of θ, the angle which FE makes with the vertical, and find what value of θ makes $P\frac{x}{y}$ a maximum.

Let r be the internal and R the external radius of the sphere, δ the weight of a cubic foot of the material of which it is composed. Then the weight P of any portion of the rib ($p\ q\ r\ s$ CD) is found by the integral calculus to be—

$$P = \delta . V = \delta . \phi (1 - \cos. \theta) \frac{R^3 - r^3}{3}$$

If g is the centre of gravity of the portion of the rib whose weight is P, and G its projection on OA; then if $OG = z$, we find the value of z by the help of the integral caculus to be, when ϕ is small—

$$z = \frac{3}{8}\frac{R^4 - r^4}{R^3 - r^3} \times \frac{\theta - \frac{1}{2}\sin. 2\theta}{1 - \cos. \theta}.$$

Now x is the perpendicular distance of gG from E; therefore

$$x = r \sin \theta - z.$$

Therefore
$$P x = \delta . \phi (1 - \cos. \theta) \frac{R^3 - r^3}{3} \times \left\{ r \sin. \theta - \frac{3}{8}\frac{R^4 - r^4}{R^3 - r^3} \times \frac{\theta - \frac{1}{2}\sin. 2\theta}{1 - \cos. \theta} \right\},$$

or

$$Px = \frac{\delta . \phi}{24} \left\{ 8r (R^3 - r^3) \sin. \theta (1 - \cos. \theta) - 3 (R^4 - r^4) (\theta - \tfrac{1}{2} \sin. 2\theta) \right\}.$$

And since $$y = \mathrm{R} - r \cos.\ \theta, \text{ and } \mathrm{N} = \mathrm{P}\frac{x}{y},$$

$$\therefore\ \mathrm{N} = \frac{\delta \,.\, \phi}{24} \cdot \frac{8r(\mathrm{R}^3 - r^3) \sin.\ \theta\,(1 - \cos.\ \theta) - 3\,(\mathrm{R}^4 - r^4)\,(\theta - \frac{1}{2} \sin.\ 2\theta)}{\mathrm{R} - r \cos.\ \theta}.$$

Let us take ϕ as the circular measure of an angle of 2°, or $\phi = \frac{\pi}{90} = \cdot 0349066$, in which case we have

$$\mathrm{N} = \cdot 001454\,\delta \frac{8r\,(\mathrm{R}^3 - r^3) \sin.\ \theta\,(1 - \cos.\ \theta) - 3\,(\mathrm{R}^4 - r^4)\,(\theta - \frac{1}{2} \sin.\ 2\theta)}{\mathrm{R} - r \cos.\ \theta}$$
$$= \cdot 001454\,\delta \times \mathrm{N}', \text{ say.}$$

We have now to find what value of θ will make N′ a maximum, and as the ordinary rules for maxima will not apply to this expression, we must find it by calculating N′ for different values of θ. This has been done for the case when $r = 10$, $\mathrm{R} = 11$, and it is found that N is greatest when $\theta = 70°$; thus

$\theta = 69°$	...	...	...	N′ = 506·034.
$\theta = 70°$	...	...	...	N′ = 506·241.
$\theta = 71°$	...	...	...	N′ = 506·018.

We have now to substitute in N the values of θ, sin. θ, &c., when the angle is 70°, or when $\theta = 35\frac{\pi}{90} = 1{\cdot}22173$, sin. $\theta = \cdot 93969$, cos. $\theta = \cdot 34202$, sin. $2\theta = \cdot 64279$.

This reduces the expression for N to

$$\mathrm{N} = \delta \frac{\cdot 007192\,r\,(\mathrm{R}^3 - r^3) - \cdot 0039273\,(\mathrm{R}^4 - r^4)}{\mathrm{R} - \cdot 34202\,r} \quad \ldots \quad \ldots \quad (1)$$

We can now transpose N and P to the point E; and in order to find the thickness of the pier or supporting wall RSTP, we proceed to take their moments, together with those of the part of the rib below EF, and the pier itself, about the outer bottom edge S of the pier.

If we call $y\mathrm{S} = b$, the perpendicular distance from S of the direction of N, then

$$b = \mathrm{H} + r \,.\, \cos.\ \theta, \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where H is the height RS of the pier or "drum."

Let $\mathrm{S}e = a$, the distance from S of a vertical dropped from E; F = the weight of the portion of the rib below EF; c = the perpendicular distance from S of a vertical from the centre of gravity of the lower portion of the rib whose weight is F; Q = the weight of the portion of the "drum" on which the rib stands, and q = the distance from S of a vertical from its centre of gravity; we have then (in equilibrium) the equation

$$\mathrm{N} \,.\, b = \mathrm{P} \,.\, a + \mathrm{Q} \,.\, q + \mathrm{F} \,.\, c, \quad \ldots \quad \ldots \quad (3)$$

which we will call the *Equation for Equilibrium.* From this equation we can find the thickness (t) of the pier necessary to produce equilibrium.

In order, however, that we may have stability in the structure, we must multiply Nb by the *coefficient of stability*, which we may take as 2. The equation from which to find the value of t then becomes

$$2\,N\,.\,b = P\,.\,a + Q\,.\,q + F\,.\,c, \quad \ldots \quad \ldots \quad (4)$$

which we will call the *Equation of Stability*.

We now proceed to find the values of P . a, Q . q, and F . c.

The value of P was previously found to be

$$P = \delta\,.\,\phi\,(1 - \text{cos. } \theta)\frac{R^3 - r^3}{3};$$

and if we substitute for ϕ and θ their values,

$$P = \cdot 007656\,\delta\,(R^3 - r^3).$$

Also $a = Se = t + r\,(1 - \text{sin. } \theta) = t + \cdot 06031\,r$; so that we find for the value of P . a,

$$P\,.\,a = \cdot 007656\,\delta\,(R^3 - r^3)\,t + \cdot 0004618\,\delta\,.\,(R^3 - r^3)\,r. \quad \ldots \quad \ldots \quad (5)$$

The value of F is found, by the same means as that of P, to be

$$F = \delta\,.\,\phi\,.\,\text{cos. } \theta\,\frac{R^3 - r^3}{3}$$
$$= \cdot 00398\,\delta\,(R^3 - r^3).$$

Let z_1 be the distance from O on OA of the perpendicular dropped from the centre of gravity of the portion of the rib whose weight is F. Then by the integral calculus,

$$z_1 = \frac{3}{8}\,\frac{R^4 - r^4}{R^3 - r^3} \times \frac{\frac{\pi}{2} - \theta + \frac{1}{2}\,\text{sin. } 2\theta}{\text{cos. } \theta}$$

And if we substitute for θ its value,

$$z_1 = \cdot 7351\,\frac{R^4 - r^4}{R^3 - r^3}$$

And $c = OR - z_1 = t + r = z_1$.

Hence we find

$$F\,.\,c = \cdot 00398\,\delta\,(R^3 - r^3)\,t + \cdot 00398\,\delta\,\{r\,(R^3 - r^3) - \cdot 7351\,(R^4 - r^4)\}. \quad \ldots \quad (6)$$

We have now to find the moment about S of the weight of the pier or supporting wall.

Let Q be the weight of the pier, δ_1 the weight of a cubic foot of its material; then

$$Q = \tfrac{1}{2}\phi\,.\,\delta_1\,\{(r + t)^2 - r^2\}\,.\,H = \tfrac{1}{2}\phi\,\delta_1\,(2r + t)\,t\,.\,H$$
$$= \cdot 017453\,\delta_1\,(2r + t)\,t\,.\,H.$$

Let $O'g'$ be the distance from O′ of the centre of gravity of the pier, $ST = t$ its thickness. Then by the integral calculus we find

$$O'g' = \frac{4}{3}\frac{(r+t)^3 - r^3}{(r+t)^2 - r^2}$$

$$= \frac{2}{3}\frac{(r+t)^3 - r^3}{(r+t)^2 - r^2} = \frac{2\,(3r^2 + 3rt + t^2)}{3\,(2r+t)};$$

$$q = Sg = O'S - O'g = r + t - O'g$$

$$= 3\,\frac{(r+t)\,(2r+t) - 2\,(3r^2 + 3rt + t^2)}{3\,(2r+t)}$$

$$= \frac{3rt + t^2}{3\,(2r+t)}.$$

We therefore obtain for the value of Qq,

$$Qq = \cdot 017453\,\delta_1\,(2r+t)\,t\,.\,H\,\frac{3r+t}{3\,(2r+t)}t$$

$$= \cdot 0058177\,\delta_1\,.\,t^2\,(3r+t)\,.\,H. \ldots \quad \ldots \quad \ldots \quad (7)$$

We can now, by adding together the several quantities (5), (6), (7), and equating to the value of Nb as found from (1) and (2), form the equation for *equilibrium* (3), which will be a cubic equation in respect of t. We shall thence find the value of t necessary to produce *equilibrium* in the structure, and, by equating the same quantities to $2Nb$, form the equation for *stability* (4), from which we get the value of t necessary to produce *stability* in the structure.

The following example will serve to show how readily these formulæ can be applied, and the use which the practical architect may make of them.

Example:—

Let $r = 30$ feet, $R = 33$ feet, $H = 80$ feet, δ and δ_1 as before.

From (1) ... ... $N = 2483{\cdot}84$;
„ (2) ... ... $b = 90{\cdot}2606$;

therefore

$$Nb = 224192{\cdot}8,$$

and

$$2Nb = 448385{\cdot}6.$$

From (5) ... ... $P\,.\,a = 8552{\cdot}71\,t + 15476{\cdot}65$;
„ (6) ... ... $F\,.\,c = 4446{\cdot}16\,t + 4094{\cdot}17$
„ (7) ... ... $Q\,.\,q = 69{\cdot}8124\,t^3 + 6283{\cdot}116\,t^2$.

Adding and reducing, the equation for *equilibrium* becomes

$$t^3 + 90t^2 + 186{\cdot}2t - 3048{\cdot}31 = 0,$$

whence $t = 4{\cdot}83$ feet for *equilibrium*.

FIG. 26.

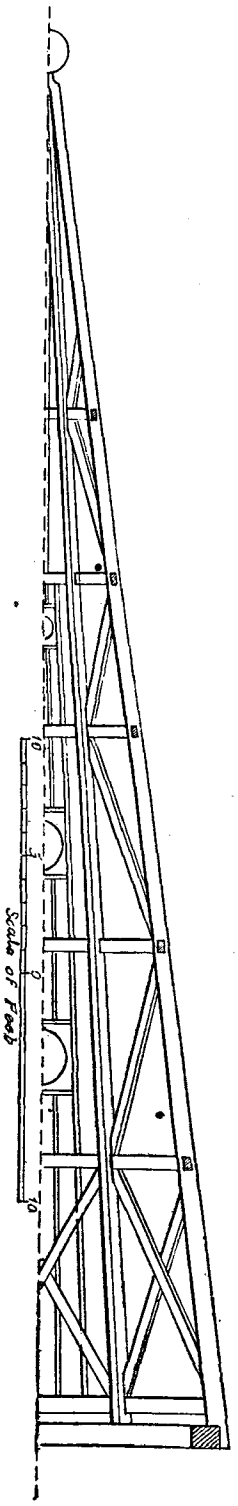
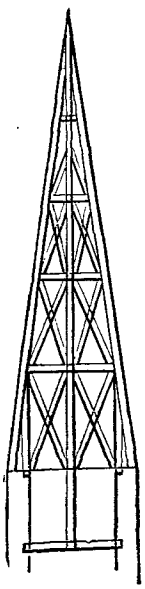


FIG. 25.



And the equation for *stability* is

$$t^3 + 90t^2 + 186{\cdot}2t - 6159{\cdot}7 = 0,$$

whence $t = 7{\cdot}07$ feet for *stability*.

Much of the thrust of a dome may be counteracted by means of an iron belt placed round it at the point where the thrust is greatest. This point has been shown to be at 70° from the crown, or 20° from the springing.

221.—When the section of the dome is a Gothic or pointed arch, the position of the joint of rupture will depend on the *pitch* of the arch; if the *pitch* is low or the section differs but little from a semi-circle, the joint of rupture will make an angle of nearly 20° with the horizontal, but if the *pitch* is high, it makes a smaller angle. Thus, for instance, if the radius drawn to the vertex makes only 10° with the vertical, the joint of rupture makes 17° with the horizontal; but when that radius makes $22\frac{1}{2}°$ with the vertical, the joint of rupture makes $13\frac{1}{2}°$ with the horizontal; and if it is at 30° with the vertical, then the joint of rupture is 10° only with the horizontal. The value of N, or the horizontal thrust at E, diminishes as the pitch increases; so that, if in the hemisphere it is 92, in the Gothic domes of the three sections above described it is 88·7, 80·4, and 77·3 respectively, the *span* being the same in all. In a parabolic dome of the same span as the above, the height being equal to half the span, the thrust is 79·6, and acts at the springing, which is the joint of rupture. If the thickness of the hemispherical dome is made to diminish upwards, so as to be half the thickness at the crown that it is at the springing, the thrust is greatly decreased, being only 55·8 in the dome of 20 feet span, as compared with 92 in the dome of uniform thickness. The papers themselves, from which the foregoing is taken, will be found complete in the *Civil Engineer and Architect's Journal* for February and March, 1868.

ON THE CONSTRUCTION OF SPIRES.

222.—A SPIRE is a cupola in which the outline is straight instead of being curved, the structure being of a pyramidal form, and having for its plan either a circle, a square, a hexagon, an octagon, or any other polygonal figure; the most usual plan being either the circle or the

octagon. A curb of timber is fixed on the top of the wall, from which the spire rises, and into this are framed the main ribs, following the slope of the spire, and meeting at the top in a point; if the plan is an octagon there are eight of these ribs, one at each angle, which are framed at their upper ends into a vertical mast, which goes down the centre of the structure, and is secured by horizontal ties, either at the base, as in *fig.* 25, or at some intermediate point, as in *fig.* 26. Horizontal purlins are framed into the main ribs at several points up the spire, and to these are fixed the rafters which carry the covering of the spire. Cross bracing is introduced to prevent the framework from being strained by the force of the wind.

Numerous examples of ancient timber spires, or *flêches*, are seen in continental buildings, and occasionally on old English churches, one of the most remarkable being that of Chesterfield, which has attracted much attraction from its twisted appearance and deflexion from the perpendicular arising from decay of some of the main timbers. Its height above the tower is 111 feet, and it is 24 feet square at the base on the inside. It has deflected 7 feet from the perpendicular, and the upper part has twisted to the extent of 60°. It was originally built square.*

The half section of the wooden spire of St. Swithin's Church, Cannon Street, London, designed by Sir C. Wren, is shown on *fig.* 26, which is taken from *Illustrations of the Parochial Churches of Sir C. Wren*, by J. Clayton (1848). This spire is octagonal on plan, is 16 feet wide at base and 56 feet in height above the tower, on which it is supported by a wooded sill, 12″ × 12″; to this the feet of the angle rafters are secured, their scantling at base being 10″ × 7″. It has five rows of horizontal purlins framed into the angle rafters, with cross braces, 6″ × 4″ between. The rafters which carry the covering are 4″ × 2″.

* A description of Chesterfield spire will be found in the *Transactions of the Royal Institute of British Architects* for 1855.

SECTION VI.

ON THE CONSTRUCTION OF PARTITIONS AND FRAME HOUSES.

ON QUARTER PARTITIONS.

223.—PARTITIONS, in carpentry, are frames of timber for dividing the internal parts of a house into rooms; they are usually lathed and plastered, and sometimes the spaces between the timbers are filled with brickwork.

In modern carpentry there is no part of a building so much neglected as the partitions. A square of partitioning is of considerable weight, seldom less than half a ton, and often much more; therefore a partition should have an adequate support: instead of which it is often suffered to rest on the floor, which, of course, settles under a weight it was never intended to bear, and the partition breaks from the ceiling above.

If it be necessary to support a partition by means of the floors or roof, it should rather be strapped to the floor or roof above it, than be suffered to bear upon the floor below; because in that case the cracks along the cornice would be avoided; and in such cases the timbers of the floor or roof must be made stronger. A partition ought, however, to be capable of supporting its own weight; for even when doorways are so placed that a truss cannot be got the whole depth, it is almost always possible to truss over the heads of the doors.

Partitions that have a solid bearing throughout their length do not require any braces; indeed, they are better without them, as it is easy to stiffen them by means of struts between the uprights, and thus the shrinking and cross strains occasioned by braces are avoided. When braces are introduced in a partition, they should be disposed so as to throw the weight upon points which are sufficiently supported below, otherwise they do more harm than good.

But though it be often practicable to give a partition a solid bearing throughout, it is better not to do so, because all walls settle; therefore, the partition should always be supported only by the walls it is connected with, in order that it may settle with them. If the partition have a solid bearing and the walls settle, fractures must necessarily take place.

Also, when a partition is supported at one end by the wall of a high part of the building and by the wall of a lower part at the other end it will always crack, either close by the walls or diagonally across.

In a trussed partition the truss should have good supports, either at the ends or

other convenient places, and the framing should be designed accordingly; that is, so that the weight may not act on any other points than those originally intended to bear it. The best points of support are the walls to which the plastering of the partition joins.

224.—Partitions are made of different thicknesses, according to the extent of bearing; for common purposes, where the bearing does not exceed 20 feet, 4 inches is sufficient; or generally the principal timbers may be made

4	inches	by 3	inches	for a bearing	not	exceeding	26	feet.
5	„	$3\frac{1}{2}$	„	„	„	„	30	„
6	„	$4\frac{1}{4}$	„	„	„	„	40	„

And partitions should be filled in with as thin stuff as possible, provided it be sufficient to nail the laths to. Two inches is quite a sufficient thickness. When these filling-in pieces, or *quarters*, as they are termed, are in long lengths, that is, when they exceed 3 or 4 feet, they should be stiffened by short struts between them; or, which is much better, we may notch a continual rail across the uprights, nailing it to each.

It should be borne in mind that in all cases useless timber is only an unnecessary load upon the framing, and increases the risk of failure at a considerable expense.

The thicknesses above mentioned apply only to partitions that have no other than their own weight to bear. When a floor is to be supported by a partition it must be prepared for that purpose. It would, however, be impossible to give any rules for such partitions, as the design must be varied according to circumstances, which differ so materially in almost every case as to render particular rules useless.

225.—When partitions of considerable strength are required, another simple method of constructing them may be employed with advantage, particularly where it is desirable to prevent the passage of sound.

Let the truss be formed of such strong timbers as may be necessary, nearly as in the usual method; but, instead of using *quarters* for nailing the laths to between the main timbers, let pieces be nailed, in the manner of battens, upon each side of the truss. A partition done in this manner occupies a little more space; but to compensate for this it has the advantage of strength and lightness, besides preventing the passage of sound better than the common mode of construction.

226.—The pressure in the direction of any of the pieces may be found by applying the principles given in Section I.; and the scantlings of the timbers that would be sufficient to sustain such pressures may be found by the rules for the stiffness of materials in Section II. The following data will assist in forming an estimate of the pressure on the framing of partitions:—

The weight of a square of partitioning may be taken at.....	from	1,480 lbs.	to	2,000 lbs.
The weight of a square of single-joisted flooring, without counter-flooring...	„	1,260	„	2,000 „
The weight of a square of framed flooring, with counter-flooring	„	2,500	„	4,000 „

As great nicety is not required in calculating the scantlings, the highest numbers may be taken for long bearings and the lowest for short ones; as the one gives the weight in large mansions, the other that in ordinary houses.

The shrinkage of timbers, and still more often imperfect joints, cause considerable settlements to take place in partitions, and consequently cracks in the plastering; therefore it is essential that the timber should be well seasoned, and also that the work should be well framed, as a slight degree of settlement in a partition is attended with worse consequences than those produced by a like degree of settlement in any other piece of framing.

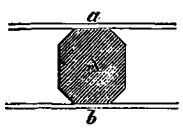
227.—*Plate* XXXIII., *fig.* 1, shows a design for a trussed partition with a doorway in the middle; the tie, or sill, is intended to pass between the joisting under the flooring boards. The strongest positions for the inclined pieces of the truss is shown by the figure, as the truss would have been much weaker with the same quantity of materials, if they had been placed in the position shown by the dotted lines. The inclination of the trussing-pieces should never greatly differ from an angle of 40 degrees with the horizon. The horizontal pieces, *a a*, are intended to be notched into the uprights, and nailed; in partitions for principal rooms one on each side might be used.

When a doorway is near to the side of a room, which is often necessary, in order to render the room either convenient or comfortable, the partition should be trussed over the top of the door, as shown in *fig.* 2. The posts, A, B, should be strapped to the truss, and braces may be put in the lower part of the truss in the common way; but it would be better to halve those braces into the uprights, which would bind the whole together.

In order to save straps, the posts A, B, are often halved into the tie CD; in that case the tie should be a little deeper; and as the tie may be always made strong enough to admit halving, perhaps this is the best method.

Partitions should always be put up some time before they are plastered, in order that the timbers may be put right again, in case they should cast. This precaution is not so necessary where timber has been a considerable time cut to the proper scantlings or well seasoned.

The arrises of all timbers exceeding 3 inches should be bevelled off, to allow room for a sufficient key for the plaster; that is, if A be the section of a post or brace, to be lathed at *a* and *b*, it must be bevelled so as to reduce the faces at *a* and *b* to less than 3 inches.



The distance of the filling-in timbers, or quarters, must be adapted to the usual lengths of the laths; these are commonly in 4 feet lengths, and then require the timbers to be 1 foot from middle to middle.

228.—The framing in the partitions shown on *Plate* XXXIII. is similar to that of a queen-post truss, the upright pieces, A, B, *fig.* 2, acting as ties to hold up the *sill* or tie-beam, and these being supported by the inclined beams or *braces*, the strain on which is the resolved part of the tension in the uprights as in the rafters of a roof, and acts as a compressive force down their length, the vertical load supported by each upright being one-third the weight of the partition. If W is the whole weight of the partition, then the compression down each brace is $\frac{1}{3}$ W divided by the *sine* of the angle of its inclination

(see Art. 209). In *fig.* 1, this angle is 40°, and *sin.* 40° = ·643, so that the compression down the brace is ·52 W; and we can determine its scantling from the equation (Art. 128),

$$\cdot 52\ \mathrm{W} = \frac{d^4}{l^2},$$

where l is the length in feet of the brace, and d^2 its sectional area, supposed square. Suppose S to be the clear span in feet between the walls, and each foot of length of the partition to weigh $\frac{3}{40}$ ton; then $\mathrm{W} = \frac{3}{40}\,\mathrm{S}$, and $l = \frac{1}{2}\,\mathrm{S}$; therefore

$$d^4 = \cdot 01\ \mathrm{S}^3.$$

This formula gives a sectional area of 9 inches for the braces, when S = 20 feet; of $16\frac{1}{2}$ inches when S = 30 feet; and of $25\frac{1}{2}$ inches when S = 40 feet.

In *fig.* 2, the angle is 18°, and *sin.* 18° = ·309; consequently the compression down the strut is 1·08 W or ·081 S; but the length l in this case is only $\frac{1}{3}$ S; consequently we have

$$d^4 = \cdot 009\ \mathrm{S}^3.$$

From which it is found that the scantling of the braces may be rather less than in the former case.

RULE. To find the minimum *sectional area* of the principal timbers of a trussed partition, divide the *cube* of the *span* (in feet) by 100, and the *square-root* of the quotient will be the area required in inches.

ON THE CONSTRUCTION OF FRAME HOUSES.

229.—FRAME HOUSES are timber constructions of which the walls are framed together in very much the same manner as quarter partitions. These generally rest at the corners upon piers of stone or brick, or sometimes the sill is bedded its whole length upon a wall, in which case no trussing is required, but only upright pieces and some cross bracing to stiffen it. The framing for a rectangular house consists of four stout upright posts at the angles framed into horizontal heads and sills, the heads being further supported throughout their length by upright quarters. The rafters of the roof are fixed at their feet on the top of the heads. The outside may be covered with *weather-boarding*, or feather-edged boards nailed to the timbers horizontally and made to lap one over the other to keep out the weather; and the inside can be covered with *matched-boarding* or with lath and plaster.

In the sixteenth century many frame houses of large size were erected in England, the timbers being left exposed on the outside and the space between them filled in with a kind of plaster called *rough-cast* laid upon lath or upon a brick filling. The inside was generally lined with oak-panelling. In many examples these houses are built in two or three stories, the story above often overhanging the one below, brackets and corbels being introduced to support the upper stories; or the ends of the floor timbers are made to project and thus form a firm basis for the wall above.

SECTION VII.

TEMPORARY STRUCTURES.

ON CENTERING, SCAFFOLDING, SHORING, AND COFFER DAMS.

ON CENTRES FOR BRIDGES.

230.—A CENTRE is a timber frame, or set of frames, erected temporarily for the purpose of supporting the arch-stones of a bridge during the construction of the arch.

The qualities of a good centre consist in its being a sufficient support for the weight or pressure of the arch-stones, without any sensible change of form throughout the whole progress of the work, from the springing of the arch to the fixing of the key-stone. It should be capable of being easily and safely removed, and designed so that it may be erected at a comparatively small expense.

In navigable rivers, where a certain space must be left for the passage of vessels, and in deep and rapid rivers, where it is difficult to establish intermediate supports, and where much is to be apprehended from sudden floods, the frames should span the whole width of the archway, or be framed so as to leave a considerable portion of the archway unoccupied. In such cases, a considerable degree of art is required to make the centre an effectual support for the arch-stones, particularly when the arch is large.

But in narrow rivers, and in those where the above-mentioned inconveniences do not interfere with the work, the framing may be constructed upon horizontal tie-beams, supported in several places by piles, or frames fixed in the bed of the river; and the construction is comparatively easy.

In large arches, when the arch-stones are laid to a considerable height, they often force the centre out of form, by causing it to rise at the crown; and it is sometimes necessary to load the centre at the crown to prevent such rising; but this is a very imperfect remedy. Notwithstanding that the subject has been considered by several very eminent men, their works are not much calculated to instruct the carpenter how to avoid this difficulty: indeed their object seems to have been exclusively to calculate the strength of a centre already designed, instead of showing the principles on which it ought to be contrived; and even in calculating the strength they are very imperfect guides, because they have not attempted to find what forces would derange a centre, but only the force that might be supported without fracture.*

* See Pitot on *Centres*, Mem. de l'Acad., 1726; Couplet on ditto, Mem. de l'Acad., 1729; Frezier's *Coupe des Pierres*.

Mr. Smeaton, in his designs for centres, always contrived his scantlings to suit the general scantlings of timber, with the view of saving labour, and of leaving the timber in as useful a state as possible when it was done with. This practice is a good one, and ought to be imitated, as a centre or a scaffold is not like a permanent work. Nevertheless, some knowledge of the principle of disposing the parts is necessary, and also of estimating the degree of stiffness that will be actually required in a centre; otherwise more timber may be wasted than if it had been cut to the proper scantling at the first, as all timber that has been used in a centre is more or less injured.

Centres are composed of several separate vertical frames or trusses, connected together by horizontal ties and stiffened by braces. When the frames have to span the whole width of the archway, the offsets of the stonework afford a most substantial abutment for the support of the centre. The frames or trusses of centres are generally placed from 4 to 6 feet apart, according to their strength, and the pressure they have to support. In general, there is one frame under each of the external rings of arch-stones, and the space between is equally divided by the intermediate frames.

A bridge of three arches will require two centres; one of five arches requires three centres, &c.

PRESSURE OF ARCH-STONES UPON CENTRES.

231.—Before proceeding to investigate the disposition and stiffness of centres, the point must be determined at which the arch-stones first begin to press upon the centre; and also the pressure upon it at different periods of the formation of the arch.

It has been found by experiment, that a stone placed upon an inclined plane does not begin to slide until that plane has an inclination of about 30° from the horizontal plane;* and until a stone would slide upon its joint, or bed, it is obvious that it would not press upon the centre. Also, when a hard stone is laid with a bed of mortar it will not slide till the angle becomes from 34° to 36°. A soft stone bedded in mortar will stand when the angle which the joint makes with the horizon is 45°, if it absorb water quickly; because in that case the mortar becomes partially set.* Similar results have been obtained by other experimentalists; therefore we may consider the pressure in general to commence at the joint which makes an angle of about 32° with the horizon.

This angle is called the angle of repose, and its tangent will represent the friction; hence, considering the pressure as unity, the friction will be 0·625. Peronet estimates the friction at 0·8;† but it is erring on the safe side to take the lower result.

The next course above the angle of repose will press upon the centre, but only in a small degree; and the pressure will increase with each succeeding course. The relation between the weight of an arch-stone, and its pressure upon the centre, in a direction perpendicular

* Rondelet, *L'Art de Bâtir.*

† *Mémoir sur le Cintrement et le Decintrement des Ponts*, in the Memoirs of the Academy of Sciences at Paris for 1773.

to the curve of the centre, may be determined from the following equation: W (sin. a − , cos. a) = P.

Where W is the weight of the arch-stone, P = the pressure upon the centre, f = the friction, and a = the angle which the plane of the lower joint of the arch-stone makes with the horizon.

When the angle which the joint makes with the horizon is	34	degrees,	P = ·04 W
.....	36	„	P = ·08 W
.....	38	„	P = ·12 W
.....	40	„	P = ·17 W
.....	42	„	P = ·21 W
.....	44	„	P = ·25 W
.....	46	„	P = ·29 W
.....	48	„	P = ·33 W
.....	50	„	P = ·37 W
.....	52	„	P = ·40 W
.....	54	„	P = ·44 W
.....	56	„	P = ·48 W
.....	58	„	P = ·52 W
.....	60	„	P = ·55 W

But when the plane of the joint becomes so much inclined that a vertical line passing through the centre of gravity of the arch-stone does not fall within the lower bed of the stone, the whole weight of the arch-stone may be considered as resting upon the centre, without material error. We have thus an easy method of estimating the weight upon a centre, at any period of the construction, or when any portion of the arch-stone is laid, as well as when the whole weight it has to sustain is upon it.

232.—As an example, let it be required to determine the pressure of the arch-stones upon 20 degrees of the centre, counting from the joint which makes an angle of 32 degrees with the horizon.

RULE. Take out of the preceding table the decimal opposite every second degree for the first 20 degrees; that is, from 32 to 52 degrees, and add them together. Multiply the sum thus found by the weight of a portion of the arch-stones comprehended between two degrees; the product will be equal to the pressure of 20 degrees of the arch upon the centre.

Suppose the frames of the centre to be 5 feet from middle to middle, and the depth of the arch-stones to be 4 feet; also, that the space comprehended between 2 degrees of the arch measured at the middle of the depth of the stone is 1·5 feet. The solid content will be found to be 30 cubic feet; and if the weight of a cubic foot of the stone be 150 lbs., the weight of two degrees will be 30 × 150 = 4,500 lbs.

Then adding together the decimals for 20 degrees, that is, from 32 degrees to 52, the sum is 2·26. This sum multiplied by the weight of two degrees, or 4,500 lbs., gives 10,170 lbs. for the pressure of 20 degrees upon one frame of the centre.

233.—It is evident from an inspection of the table, that the pressure increases very slowly till the joint begins to make a considerable angle with the horizon; and it is of importance to bear this in mind in designing centres, because the strength should be directed to the parts where the strain is greatest. For instance, at the point where the joint makes an angle of 44 degrees with the horizon, the arch-stone only exerts a pressure of one-fourth of its weight upon the centre; where the angle of the joint is 58 degrees, the pressure exceeds half the weight; but near to the crown the stones rest wholly upon the centre. Now it would be absurd to make the centre equally strong at each of these points; besides by such a method there would not be the means of applying the strength where it is really required, without interfering with ties and braces, which are only an incumbrance to the framing.

When the depth of the arch-stone is nearly double its thickness, the whole of its weight may be considered to rest upon the centre at the joint which makes an angle of about 60 degrees with the horizon. If the length be less than twice the thickness, it may be considered to rest wholly upon the centre when the angle is below 60 degrees; and if the length exceed twice the thickness, the angle will be considerably above 60 degrees before the whole weight will press upon the centre.

234.—But though the error introduced, by considering all the arch-stones above the joint that makes an angle of 60 degrees with the horizon, as pressing wholly on the centre, is not a very considerable one, it may be desirable to use a method which approaches nearer to the truth when the arch is circular. However inclined a joint may be, a certain portion of the force of the arch-stone will be lost in friction, except when the joints become sensibly vertical. And, in any case, the pressure perpendicular to the curve of the centre will be expressed by the equation W (sin. $a - f$ cos. a) = perpen. pressure = P. But it will be more convenient to measure the angle a from the vertical line passing through the crown: then W (cos. $a - f$ sin. a) = P.

If the angle included between the joints of one arch-stone be denoted by θ, and the stones be alike in weight, and in the portion of the arch they occupy, then the pressure of any number n of arch-stones upon the centre will be expressed by the equation,

$$\left(\frac{\text{cos.}\,\frac{n}{2}\,\theta \times \text{sin.}\,\frac{n+1}{2}\,\theta - f\,\text{sin.}\,\frac{n}{2}\,\theta \times \text{sin.}\,\frac{n+1\,\theta}{2}}{\text{sin.}\,\frac{1}{2}\,\theta}\right)^{*} = \text{pressure} = \text{P}.$$

The magnitude of the arc θ being ascertained, the sines and cosines may be taken from a table of natural sines. But the calculation will be more simple under the following form:—

$$\frac{\text{W} \times \text{sin.}\,\frac{n+1}{2}\,\theta}{\text{sin.}\,\frac{1}{2}\,\theta} \times (\text{cos.}\,\tfrac{1}{2}\,n\,\theta - f\,\text{sin.}\,\tfrac{1}{2}\,n\,\theta) \quad . \quad . \quad . \quad . \quad \text{(A)}$$

The computation becomes easier by using a table of logarithms.

When the arch-stones are small, the pressure upon the centre is greater than when they are large; and as an arch-stone will seldom be smaller than would extend one degree of the arch, the pressure in that case may be assumed as sufficiently accurate: the error being always in excess till the arch-stones are less than one degree each. Now the number of degrees between the middle or crown and the angle of repose is 58; therefore, by equation

* This expression is equal to W (sum of cosines of $n\,\theta - f \times$ sum of sines of $n\,\theta$), and the sum of the sines and cosines are found by equations 27 and 29, of Dr. Hutton's *Course of Mathematics*, vol. iii.

(A) the whole pressure upon the semi-centre may be determined. The calculation by logarithms may be made as below; and the equation, in this case, is more conveniently arranged as follows:—

$$W \times \left\{ \frac{\cos. \frac{n}{2}\theta \times \sin. \frac{n+1}{2}\theta}{\sin. \frac{1}{2}\theta} - \frac{f \times \sin. \frac{n}{2}\theta \times \sin. \frac{n+1}{2}\theta}{\sin. \frac{1}{2}\theta} \right\}$$

Here if $\theta = 1$ degree, $n = 58$, and (Art. 231) $f = 0{\cdot}625$, we have—

Log. cos. $\frac{n}{2}\theta$ = log. cos. 29° ... ... = $\bar{1}{\cdot}941819$	Log. f = log. ·625 ... ... = $\bar{1}{\cdot}795880$
Log. sin. $\frac{n+1}{2}\theta$ = log. sin. 29° 30′ ... = $\bar{1}{\cdot}692339$	Log. sin. $\frac{n}{2}\theta$ = log. sin. 29° ... ... $\bar{1}{\cdot}685571$
The sum of which ... ... = $\bar{1}{\cdot}634158$	Log. sin. $\frac{n+1}{2}\theta$ = log. sin. 29° 30′ ... = $\bar{1}{\cdot}692339$
Log. sin. $\frac{1}{2}\theta$ = log. sin. 0° 30′... ... = $\bar{3}{\cdot}940842$	The sum of which ... ... = $\bar{1}{\cdot}173790$
Substracting the latter from the former, we get	Log. sin. $\frac{1}{2}\theta$ = log. sin. 0° 30′ ... ... = $\bar{3}{\cdot}940842$
	Substracting we get
Log. 49·36 ... ... = 1·693316	Log. 17·1... ... ... 1·232948

And 49·36 − 17·1 = 32·26; consequently 32·26 W is equal to the pressure of the semi-arch upon the centre, where W is the weight of a part of the ring of arch-stones, each measuring one degree.

ON DESIGNING CENTRES.

235.—In designing frames for centres, there are two things which require particular attention. The centre should be sufficiently strong to support any part, or the whole of the pressure; and it should be capable of supporting any part without a sensible change of form. To accomplish the first object, the strains must not act very obliquely upon the supporting pieces; and the magnitude of the parts must be proportional to the strain upon them. The second object will be obtained by disposing the parts so that the stress may prevent any part rising, instead of causing it to rise, as is too commonly the case in centres.

236.—Centering for arches of small span is easily managed; and when it is possible to obtain intermediate supports at a comparatively small expense, even large centres are not difficult. The centering of Conon Bridge, of which the span is 65 feet, and rise 21·8 feet, is a good example of this kind of construction: it was designed by Mr. Telford.* (See *fig.* 1, *Plate* XXXIV.)

A very simple and effective centre for an arch of small span is that which was used for a viaduct on the Chatham and Dover Railway, as shown on *Plate* VI. of Haskoll's *Bridges and Viaducts*.† The span in this case is 26 feet, and the circular rib on which the arch rests is supported by five struts, at points which divide the circumference into six equal parts; the lower ends of the struts being fixed to a horizontal beam having one central prop.

* *Edinburgh Encyclopædia*, Art. "Bridge."

† Crosby Lockwood & Co.

The justly celebrated Smeaton designed the centre, *fig.* 3, *Plate* XXXIII., for Coldstream Bridge; and as an illustration we cannot offer the reader anything better than his own description which accompanied the design. He says: "What I had, therefore, in view was to distribute the supporters equally under the burden, preserving at the same time such a geometrical connection throughout the whole, that if any one pile, or row of piles, should settle, the incumbent weight would be supported by the rest."

"With respect to the scantlings," he adds, "I did not so much contrive how to do with the least quantity of timber, as how to cut it with the least waste; for, as I took it for granted the centre would be constructed of East Country fir, I have set down the scantlings, such as they usually are, in whole balks, or cut in two lengthways." The bridge was of stone; 25 feet wide from outside to outside; the centering consisted of five frames, or ribs, framed in the manner represented in *fig.* 3. The span of the centre arch was 60 feet 8 inches, and the dimensions of the principal timbers are figured upon the design.

237.—But where intermediate supports cannot be obtained, centres require to be constructed with more care; more attention is also necessary in forming the design. It is obvious that laying a load upon the haunches must have a tendency to raise the centre at the crown, unless the frame be so contrived that it cannot rise there under the effect of any force that it may have to sustain at the haunches. This principle has not been properly understood by some engineers, and some of these centres have in consequence undergone a change of form with every course of stones that was laid upon them. We cannot perhaps show better the importance of the principle of preventing any change of form by the disposition of the framing than by pointing out the defects of the centre designed by Perronet for the Bridge of Neuilly, and comparing it with some others that have been employed. *Fig.* 2, *Plate* XXXIV., represents the centre of the Bridge of Neuilly. It is obvious that such a centre, loaded at A and B, must rise at C; and the timbers being nearly parallel, the strains produced by a weight resting on any point must have been prodigious; consequently, the yielding at the joints was very considerable. It is a kind of framing well enough adapted to support an equilibrated load, distributed over its whole length; but is one of the worst that can be adopted for a centre, or for supporting any variable load. It must have consumed an immense quantity of timber, without possessing the advantage of connection. The quantity is crowded into so small a space that it has a light appearance, and consequently has obtained the approbation of those who are incapable of penetrating further than the apparent surface of the things they pretend to examine. The centres for the bridges of Nogent, Cravant, St. Maxence, and Nemours were designed on similar principles, and were found to be equally defective.

238.—*Fig.* 3, *Plate* XXXIV., represents the centre of Waterloo Bridge, over the Thames, designed by the late Mr. Rennie. In this centre, by a better disposition of its timbers, a load at A could not cause the centre to rise at C, without reducing the length of the beam DE and the one opposite to it. There is an excess of strength in some of its parts, and it is complicated in the extreme; but, on the whole, it is a very judicious combination. The centre of old Blackfriars Bridge, built in 1760, but now replaced by an iron structure, appears to have been taken as the groundwork; and there are some improvements, both in form and construction, which do much credit to the able engineer who made them.

239.—Let the line ACA′, *fig.* 1, *Plate* XXXV., represent the curve of an arch; and let us

suppose the arch-stones to begin to press upon the centre at B, B′, where the joints make an angle of 32 degrees with the horizontal plane; and that the laying of the arch-stones proceeds alike on each side. Now if two trussed frames, EDH, E′D′H, abut against each other at C, the point C cannot rise in a sensible degree from the pressures at D, D′, and much additional security may be obtained by adding the piece FF′, with the pieces FI, F′I′.

The framing of this centre commences on each side, nearly at the point where the arch-stones first begin to press upon the centre; the curved rib must be strong enough to bear the parts between BD and DC, but the bearings may be shortened by making the abutting blocks at D, D′ longer. The beams EC, E′C, will act as ties till the arch-stones are laid beyond the points D, D′; they will then begin to act as struts, and will continue to act as struts after that, till the whole is laid.

This disposition cannot be employed where the span is large, because it then requires very long pieces of timber; and the points of support for the curved rib become too far apart to be supported by timbers of the usual dimensions.

240.—Let the built beams EF, FF′, and F′E′, *fig.* 2, *Plate* XXXV., be each trussed, and abut against each other at F and F′; then it is obvious, that when the loads press equally at D, D′, they will have no tendency to raise the beam FF′ in the middle, unless it be not sufficiently strong to resist the pressure in the direction of its length; and as it is easy to give it any degree of strength that may be required, a centre of this form may, with a little variation in the trusses, be applied with advantage to any span which will admit of a stone bridge. When timber is not to be had of sufficient length, the beams EF, FF′, and F′E′ may be built in the manner directed for building beams. (See Section IX.)

In the new London Bridge the arches are of very considerable span, the centre one being 152 feet, with a rise of 37½ feet; but, by supporting the centre from the bed of the river, the skill required to span a large opening was avoided. The ribs consisted of trussed frames with horizontal tie-beams, like the central portion in *fig.* 2, *Plate* XXXV., and were supported by well-driven piles, so as to leave the central part of the arch open for navigation. Hence the design is a combination of the two methods described in Arts. 236 and 237; and the construction to effect this purpose is simple and judicious; we, however, prefer the mode of supporting from the piers in such a case.

The examples and remarks already given will furnish the reader with a clear notion of the kind of arrangement which is proper for a centre; it would be an easy matter to multiply examples, but having said enough to show the nature of the principle, we must leave him to design for himself, and proceed to make some remarks on the construction.

ON THE CONSTRUCTION OF CENTRES.

241.—The principal beams of a centre should always abut end to end when it is possible. It is a very good method, where timbers meet at an angle, to let them abut into a socket of cast iron, as has been done in the centre of Waterloo Bridge. See E, *fig.* 3, *Plate* XXXIV. The timbers should intersect one another as little as possible, as every joining causes some degree of settlement, and halving the timbers together always destroys nearly half their

strength. The pieces which tend towards the centre, and which perform a similar office to the king-post of a roof, should be notched upon the framing; and they should be in pairs, that is, one on each side of the frame, and well bolted together. Most of the braces may also be applied in the same manner with much advantage. The braces marked *a a*, in *fig.* 2, *Plate* XXXV., are supposed to be done in this way.

Ties should be continued across the frames in different parts, particularly at any point where many timbers meet; and diagonal braces across the frames are also necessary to secure them from lateral motion.

A sound and firm centre is a most desirable thing in the construction of an arch, as the motion of a weak one destroys the cohesion of the cementing materials. Sometimes centres have completely failed. In erecting a large arch over the river Derwent, on the line of the Glossop and Sheffield road, in the year 1819, as the workmen were proceeding to lay the key-stone, the centre gave way, and fell with a tremendous crash into the river. Several lives were lost in consequence.

ON REMOVING CENTRES.

242.—The frames or principal supports of a centre should be placed upon double wedges, or sometimes they may be placed upon blocks with wedge-formed steps cut in them; and when the centre is to be eased, the wedges, or wedge-formed pieces, are driven back so far as to suffer the centre to descend regularly. This operation should be very leisurely performed; in order that the arch, in taking its proper bearing, may not acquire any sensible degree of velocity; as it would be a dangerous experiment to let it settle too rapidly.

The centre, as Alberti has directed, should always be eased a little, as soon as the arch is completed, in order that the arch-stones may take their proper bearings before the mortar becomes hard. If the mortar be suffered to dry before the centre be lowered, the arch will break at the joints in settling, and the connection of the arch will be destroyed.

In small centres the wedges are driven back with mauls, men being stationed at each pair of wedges for that purpose. But in larger works a beam is mounted, as a battering ram, to drive the wedge-formed blocks back. Before driving back the wedges, it is a good precaution to mark them, so that it may be easy to ascertain when they are regularly driven.

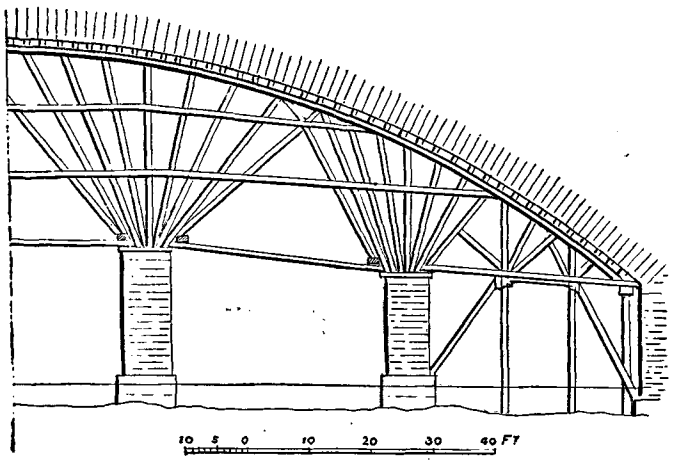
It is a great advantage in striking centres to be able to suffer them to rest at any part of the operation; and in this, as well as in some other respects, the above method of lowering and easing centres is greatly superior to that adopted by some engineers, which consists in destroying, by little and little, the ends of the principal supports, a work of difficulty as well as of danger, and which cannot be done with so much regularity as by wedges.

The centres of old Blackfriars Bridge and the Waterloo Bridge were placed upon blocks, with wedge-formed steps cut in them, as is shown in *fig.* 3, *Plate* XXXIV. Another method consists in forming the steps on beams that reach across the whole width of the bridge, passing between the feet of the trussed frames and the posts that support them. In *fig.* 1, *Plate* XXXV., the centres are supposed to be done in this manner. The frames being thus placed upon continued wedges, the centre may be struck without its being necessary to have workmen beneath: it is therefore less dangerous, and can be done with a less number of men. In consequence of nine men having been killed in removing the centre of a military

work, a similar method to the above was proposed, and used at Chatham in 1807, with success.

243.—In the erection of the Chester Bridge, finished in 1833, an entirely different principle was adopted in the construction and the mode of relieving the centre. This arch is the segment of a circle of 140 feet radius; the span is 200 feet, and the rise 42 feet. The centre consisted of six ribs in width, and the span of the arch was divided into four spaces, by means of three nearly equidistant piers of stone built in the river, from which timbers spread like a fan towards the soffit, so as to take their load endwise, as shown in *fig.* 27. The lower extremity of these radiating beams rested on cast-iron shoe-plates on the tops of the piers, and their upper ends were bound together by two thicknesses of 4-inch planking, bending round as nearly as they could be made in the true curve of the arch. On the rim thus formed, the ledging or covering, which was $4\frac{1}{2}$ inches thick, was supported over each rib by a pair of folding wedges, 15 or 16 inches long by 10 or 12 inches in breadth, and tapering about $1\frac{1}{2}$ inches: for every course of arch-stones in the bridge, therefore, there were six pairs of striking wedges. The horizontal timber in the centre was only 13 inches deep, and the six ribs were tied together transversely near the top by bolts of inch iron which passed through. The material used was fir, of whole or half timber.

FIG. 27.



This centre thus differs essentially from any other hitherto employed; each rib, instead of forming one connected piece of framework, consists here of four independent parts, and little or no transverse strain has to be resisted. Moreover, as the wedges are in this construction borne by the centre, instead of the centre being borne by them, it is obvious that the bearings may thus be gradually relieved or tightened at one place and slackened at another, according to the symptoms shown by the arch, as its support is removed, and the stonework comes to its bearing. The engineer of this bridge was Mr. Hartley, but the designer of the centre was Mr. Trubshaw; the principle he adopted being to arrange the timber so as to have the strain all in a vertical direction, doing away with much horizontal tying, which is apt to derange the framing; and to ease immediately under the covering, instead of under the sill of the centre, which is the usual plan. The method of striking is to keep up the crown, and let the haunches down, while the mortar is soft. (For further information relative to this erection, see Vol. I., *Transactions of the Institute of Civil Engineers.*)

ON COMPUTING THE STRENGTH OF CENTRES.

244.—It fortunately happens that simple designs are best calculated for centres; for it would be very difficult to form anything like an accurate estimate of the strength of a complicated one. We will here show some approximate methods of fixing upon the proper scantlings for the timbers for the designs which have been given; and add to one of them some examples in numbers, which will serve to illustrate the subject.

In the centre, *fig.* 1, *Plate* XXXV., the stress may be considered, in as far as it tends to strain the frame EDH; also the stress upon the pieces EH, H′E′, when the whole load is upon them; and, lastly, the strain upon the posts GK, G′K′.

First, let the pressure of the arch-stones between B and C be calculated, if the arch be circular, by Art. 234; and if it be elliptical, by Art. 231. Consider half this weight as collected at D, and acting in the direction DF, which will be sufficiently accurate for our present purpose. Then, by attending to the rules in Arts. 14 and 9, Section I., the strains in the directions of each of the beams composing the frame EDH will be found; and the dimensions of the pieces which would resist them are to be determined by the rules for the stiffness of beams in Section II., or by the rule at the end of this article.

Secondly, compute the pressure of the arch between D and C, and consider it as acting at C in a vertical direction; then the strain on the beams EH, H′E′, will be found by the rules above referred to.

Lastly, let the whole pressure of the arch-stones between B and C, together with half the weight of the centre itself, be considered as acting at the point E in a vertical direction, and find the dimensions of the supports KG, K′G′, that would resist this pressure.

But in these calculations it must be observed, that if the length of any of the pieces in feet be not greater than 1·25 times the breadth, or least dimension in inches, it will cripple at the joint rather than bend. Thus, if a piece be 8 inches in breadth, then its length must be 1·25 × 8, or 10 feet; otherwise it will sink at the joint rather than bend.

Therefore, when the length between the points where it is braced is less than in this proportion, instead of finding the scantlings by the rules for the stiffness of beams, they must be determined by the following rule.

RULE. The pressure upon the beam in lbs. divided by 1,000 gives the area of the piece in inches, or that of the least abutting joint, if that joint should not be equal to the section of the piece.

As all long pieces in a centre may be rendered secure against bending by cross braces or radial pieces notched on and bolted to them, this rule may in nearly all cases, be applied for centres, instead of the rules in Section II.

245.—In the centre, *fig.* 2, *Plate* XXXV., the beams EF, FF′, and F′E′, constitute the chief support; the arch is an ellipsis, and consequently a considerable part of it will bear almost wholly upon the centre. But from what has been shown respecting the pressure of the arch-stones, it will appear that if we take the whole weight of the ring between D and C, and consider it to act in the direction HF at the joining F, it will be the greatest strain that can possibly occur at that point from the weight of the arch-stones. Produce the line HF to f, and make hf to represent the pressure. Draw he parallel to the beam EF. Then, as hf

represents the pressure of the arch between D and C, *h e* will represent the pressure in the direction of the beam FE; and *e f* the pressure in the direction of the beam FF′; and these beams must be of such scantlings as would sustain these pressures.

Let the weight of the arch from H to H′ be estimated, and if two-thirds of this weight be constructed to act at C in a vertical direction, it will be the greatest load that is likely to be laid at that point, and the dimensions for the parts of the truss FCF′ must be found so as to sustain that pressure.

The frame, EDF, may be calculated to resist half the pressure of the arch-stones between B and H; that pressure being found by Art. 231.

The whole weight of the arch-stones from D to C, together with the weight of the centre itself, may be considered as acting in a vertical direction at E, and the supports at GE should be sufficient to sustain the action of this pressure.

To determine the scantlings of the ribs which support the weight between H and C, or D and H, &c., calculate the weight of that part of the arch which rests upon them, and consider it as a weight uniformly diffused over the length. The proper scantlings will then be found by the rule in Art. 96. These bearings may be much shortened by lengthening the blocks against which the inclined beams of the truss abut.

EXAMPLES.

246.—*Example* 1. Let it be required to determine the principal scantlings for a centre for a stone arch 50 feet span to the design *fig.* 1, *Plate* XXXV.; supposing the cubic foot of the stone to weigh 130 lbs., the depth of the arch-stones to be 3 feet, and the frames 5 feet from middle to middle.

The arch is described with a radius of 26 feet; consequently, 27·5 feet is the radius of an arc passing through the middle of the depth of the arch-stones: and to find the length of this arch for one degree, multiply the length of the arch for one degree for a radius of unity, which is ·01745329, by 27·5. This gives for a product ·48.

And $5 \times 3 \times \cdot48 = 7\cdot2$ feet, the solid content of one degree of the ring of arch-stones. But by Art. 234, $W \times 32\cdot26 = 7\cdot2 \times 32\cdot26 \times 130$ lbs. = 30,195 lbs., for the pressure of that part of the ring between B and C. Now suppose this pressure to act in the direction DF, and in order to render the operation more simple, call it 31,000 lbs. Draw *d f*, in No. 2, *Plate* XXXV., parallel to DF; set off *d f* equal 31 parts, by any convenient scale; and draw *e h* parallel to the beam EH; also draw *d e* and *d h* parallel to the principal rafters of the frame EDC. Now when *d h* is measured by the same scale as *d f*, it will measure seventy parts; and as both the rafters make the same angle with the straining force, the strain on each will be 70,000 lbs. Let the abutting joint be equal to the section of the rafter, then $\frac{70000}{1000} = 70$ inches, for the area of the section of each rafter, or nearly $8\frac{1}{2}$ inches square. The strain in the direction of the length of the tie-beam EH need not be calculated, because when it is sufficiently strong to resist the other strains to which it is exposed, its strength to resist tension will always be above what is necessary.

Our next operation is to calculate the weight or pressure of the arch-stones between B and

C. This may be done by common arithmetic, according to the method pointed out in Art. 234, which will show the superiority of the logarithmic process. The weight of one degree of the ring is the same as before, that is, W = 7·2 × 130 = 936 lbs., and the space between B and C is 32 degrees, therefore $n = 32$. Hence $\cos. \frac{1}{2} n\theta - f \sin. \frac{1}{2} n\theta = \cos. 16° - f \sin. 16° =$ ·96126 − ·27564 × ·625 = ·788985. And $\frac{W \sin. \frac{n+1}{2}\theta}{\sin. \frac{1}{2}\theta} \times ·788985 = \frac{936 \times ·284}{·00873} \times ·788985$ = 24022 lbs., the pressure of the part BC upon the centre.

By drawing lines parallel to the directions of the straining force and the beams, we find the pressure in the direction of the beam EH to be nearly 23,000 lbs.; therefore, $\frac{23000}{1000}$ = 23 inches, the area of the section of the beam; but it must be made a little larger than this, in order to have abutments for the other parts of the truss.

To find the dimensions of the supports required at KG, we have given an approximate rule in Art. 244: and calculating according to this rule,

The pressure on the centre has been found to be	31,000	lbs.
The weight of half the centre may be stated at...	5,000	„
Therefore the vertical pressure at K will be ...	36,000	„

This force would produce a pressure of nearly 41,000 lbs. in the direction KG; hence $\frac{41000}{1000}$ = 41 inches, the area of the support required at K.

Example 2. To find the strain upon the principal supports of the centre, in *fig.* 2, *Plate* XXXV.; the depth of the arch-stones being 5 feet, the frames 5 feet from middle to middle, and the stone 130 lbs. per cubic foot. The pressure of the arch-stones upon the centre, estimated by the methods detailed in Art. 232, will be about 130,000 lbs.; and measuring the proportions of the forces by the diagram, No. 3, *Plate* XV, the pressure in the direction of the beam FF′ will be 220,000 lbs., and the pressure in the direction FE will be 230,000 lbs.; consequently, the area of the horizontal beam should be 220 inches, and may consist of two beams 10 inches by 11 inches. The area of the inclined beam, EF, should be 230 inches, and may consist of two beams, 11 inches by 10½ inches each.

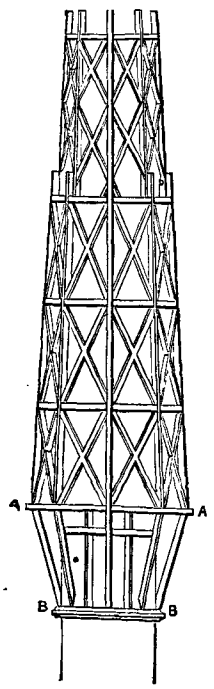
ON THE CONSTRUCTION OF SCAFFOLDING.

247.—The ordinary scaffolding erected round a brick building for the purposes of enabling the workmen to carry up the walls, can hardly be considered as a piece of carpentry, as it consists merely of upright and horizontal poles called *standards* and *ledgers* tied together by ropes, and stiffened with cross bracing, on which short pieces called *putlogs* are supported, their inner ends resting in the wall and forming a support for a few planks on which the bricklayers stand to their work. In heavy works which are faced with stone, a strong scaffolding or staging of timber is erected which is sometimes called a *gantry*, and this

requires the skilled labour of the carpenter to frame together: for although it is only a temporary structure, yet it often has to sustain heavier loads than many permanent ones, A gantry is formed of whole timber, and consists of uprights or *standards* 10 to 15 feet apart. firmly secured in the ground, on the top of which are similar pieces of timber laid horizontally, and called *runners;* and in order to prevent the end of the standards from injuring the runners, flat pieces of wood are placed between them as caps to the standards. The runners are further strengthened by oblique struts or braces resting at their lower ends on blocks fastened to the standards, their upper ends abutting against the end of a straining piece fixed close under the runners. The arrangement of this kind of framing is shown in the timber bridge, *fig.* 3, *Plate* XXXVI. When it is not convenient to let the standards into the ground, they are mortised into a horizontal sill or baulk of timber, and firmly secured with *scaffold-cramps* or with iron straps and bolts. These scaffoldings are usually in pairs, 15 to 20 feet apart, and have a travelling crane moving along the top on iron rails, by means of which heavy loads can be hoisted to any part of the work. If the building is lofty, the scaffolding is divided into stages by means of transoms or horizontal pieces fixed transversely and projecting several feet beyond the standards; another set of standards, runners, and braces are then erected on the top of the first, and are strutted from the projecting outer ends of the transoms to render them secure.

Such a scaffolding or gantry was erected over the Nelson Column at Trafalgar Square, London, of which the total height was 180 feet. It was divided into seven stages of varying heights, that of the lowest being 48 feet, and of the top one 21 feet. The standards were tenoned a short distance into the transoms, which latter projected 6 feet beyond the outer standards to support the flying *wind-braces* by which the whole structure was stiffened.

FIG. 28.

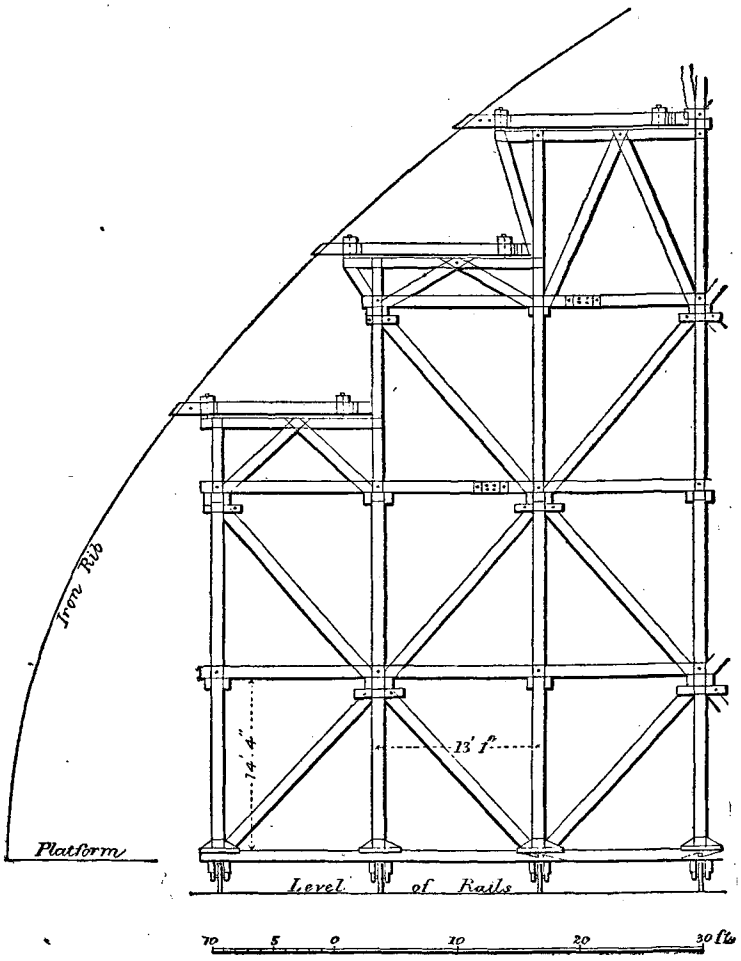


248.—In erecting lofty towers or chimney stalks, an external scaffolding can often be dispensed with, a staging being erected inside the tower and made to rise with it. In this way the towers of the Houses of Parliament at Westminster were carried up. A strong trussed frame being constructed over the whole area of the Victoria tower, consisting of baulks of timber 14 inches square and 51 feet long, with similar pieces all round the walls, and diagonal pieces at each angle. This staging was made to rise 3 feet at a time by means of screw-jacks, and the hoisting was done by means of three cranes worked by steam, which travelled on a circular rail laid all round the stage, so that materials could be hoisted and lowered at any point. The pinnacles at the four corners, which rose 85 feet above the cornice, were erected by means of a cradling scaffold erected around each as shown by *fig.* 28. This cradling was entirely independent of the masonry, which was erected within it, and derived its support from a skeleton framed platform A, A, whose timbers passed horizontally through apertures on each side of the octagonal pinnacle; these were bolted together and supported at each angle by raking-struts, AB, bearing upon the stone cornice B, B. On this platform the scaffolding was carried up in three stages, with eight standards inclined slightly inwards, and strengthened with cross-bracing and horizontal ties at each stage, the whole being securely held together with iron straps and bolts. The part of the cradling above the third stage

was formed of ordinary scaffold poles tied together with cord. The total height from the ground to the top of the pinnacles is 325 feet. (See *Transactions of the Royal Institute of British Architects* for 1857.)

249.—TIMBER-STAGING is often required for the erection of iron roofs of large span, a portion of that used for putting together the roof of the St. Pancras Station of the Midland Railway is shown on *fig.* 29. This roof was 240 feet span and 100 feet in height, the principals being 25 in number and 29 feet apart. To save the expense of erecting a scaffolding the whole length of the building, the staging was constructed 40 feet wide, so as to include two ribs of the roof, and was placed upon grooved wheels running on iron rails, so that when one pair of ribs was erected it could be moved on to the next pair. On account of the difficulty attending the moving of such a large mass of staging, it was constructed in three parts, each of which could be moved separately. The main horizontal framing was of double timbers 6″ × 6″, with the axle boxes fixed so that the wheels, 123 in number and 30 inches diameter, ran between the timbers upon 19 lines of rails. The cross framing was 12″ × 12″, and bolted to the lower framing; and on these were fixed cast-iron sockets to receive the feet of the standards and braces. The standards were 76 in number, two sets being placed under each rib; the lower portion of each standard up to a height of 29 feet 8 inches was 12″ × 12″; the next length of 29 feet 2 inches was 10″ × 10″, fitted into a cast-iron cap; the rest of the standards being 9″ × 9″ to the top of the stage. Where the stage passed under the ribs platforms were constructed fitted with timber slides which clipped the rib firmly. At a height of 13 feet 4 inches from the rails was a line of longitudinal *walings* 12″ × 6″, and above them the transverse *walings;* 14 feet 4 inches above which was a second floor of horizontal bracing; at 14 feet 4 inches above this was the third set of walings and bracing; the central compartment having seven sets of walings and four floors of horizontal bracing; while the two side portions had five floors of walings and three of horizontal bracing; the walings being in all cases double, or one on each side of the standards. The whole stage was braced strongly with diagonals, which abutted against the main standards

FIG. 29.

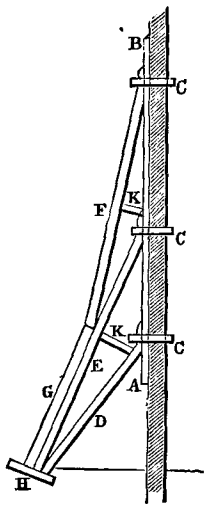


and walings, and tightly wedged up. (For a full description of the mode of using this staging see *Transactions of the Royal Institute of British Architects*, 1872.)

250.—SHORING is a framing of rough timbers fixed against an old wall in order to render it secure during the process of alteration or partial rebuilding. The tendency of the wall being to fall outwards when the lateral supports are removed, a piece of timber, called a *raking-shore*, is fixed firmly against it in an inclined position, as D and E (*fig.* 30).

A plank or *waling-piece*, AB, is fixed in an upright position against the wall, and through it is driven a horizontal piece of wood or *needle*, as C, which passes completely through the wall. Another plank, or *template*, is firmly bedded in the ground in an inclined position, at some distance from the wall, as H; and the raking-shore, D or E, is tightly fixed by means of wedges between H and C, so as to act as a temporary buttress. The weight of the wall above the needle C presses down the shore and prevents it from lifting, which it would tend to do if the wall moved outwards about its base. In lofty walls a raking-shore is generally fixed about half-way up the shore E, as F, resting on a piece G; such a shore, however, is of very little use unless there is a considerable weight of wall above the top of it to keep it from overturning about its base. In order to stiffen the shores and prevent them from *sagging*, or bending in the middle, the struts, K, are usually introduced.

FIG. 30.



NEEDLING is a shoring by means of upright shores, and is employed when the lower part of a wall has to be removed or rebuilt without disturbing the upper part. A hole is cut through the wall and a large baulk of timber, or *needle*, is firmly fixed therein, being held up by two vertical shores firmly wedged on a template laid horizontally on the ground.

251.—The strains to which a raking-shore, as E, is subjected may be determined as follows:—Let W be the weight of the wall above the foot of the shore, acting vertically down its centre, H its height; then we suppose some horizontal force F to act at B near the top of the wall, which force the shore has to sustain; let $2t$ be the thickness of the wall; then when F is about to overturn it we have in equilibrium,

$$F \times H = W \times t.$$

Let h be the height from the base to the top of the shore, and suppose P to be the pressure of the shore against the wall, so that

$$P \times h = F \times H = W \cdot t,$$

$$\text{or } P = W \frac{t}{h}.$$

Let w be the weight of the piece of wall above the top of the shore, Q that of the shore itself, l its length, and θ the angle it makes with the horizon. When the forces just balance, we have by taking moments about H, the shore-foot,

$$w\,(t + l \cos.\,\theta) + Q \frac{l}{2} \cos.\,\theta = P \cdot h = W.\,t.$$

Put x for the distance of the shore-foot H from the wall, then $x = l \cos.\,\theta$; therefore,

$$w = \frac{W \cdot t - Q \frac{x}{2}}{t + x}.$$

The compression down the shore is the sum of the resolved parts of w and P, or

$$w \sin.\ \theta + \mathrm{P} \cos.\ \theta = w\frac{h}{l} + \mathrm{W}\frac{t}{h} \cdot \frac{x}{l} = \mathrm{S};$$

then by Art. 128, we determine its strength in tons from

$$\mathrm{S} = \frac{d^4}{l^2}.$$

There is also a transverse strain acting at right angles to the shore which we call T, in tons, then

$$\begin{aligned} \mathrm{T} &= (\mathrm{Q} + w) \cos.\ \theta + \mathrm{P} \sin.\ \theta \\ &= (\mathrm{Q} + w)\frac{x}{l} + \mathrm{W}\ \frac{t}{l}; \end{aligned}$$

and as this load is distributed we may use the formula of Art. 96 for stiffness of beams, and determine the scantling from the equation,

$$b \cdot d^3 = 14\ \mathrm{T} \cdot l^2.$$

The stiffness, however, is generally increased very much by the strut K, in which case it will not be necessary to use this last formula.

Example.—Let H = 30 feet, $2t = 1\frac{1}{2}$ feet, $x = 5$ feet; and suppose the wall to be 12 feet frontage, and its weight ·05 ton per cubic foot, so that 1 foot height of wall will weigh ·9 ton, and therefore W = 27 tons. Let Q = ·2 ton, then

$$w = \frac{27 \times \cdot 75 - \cdot 2 \times 2 \cdot 5}{5 + \cdot 75} = 3 \cdot 435 \text{ tons.}$$

Therefore, $\mathrm{H} - h = \frac{3 \cdot 435}{\cdot 9} = 3 \cdot 82$ feet, or $h = 30 - 3 \cdot 82 = 26 \cdot 18$ feet, and $l = 26 \cdot 65$ feet.

$$\mathrm{S} = \frac{3 \cdot 435 \times 26 \cdot 18}{26 \cdot 65} + 27\ \frac{\cdot 75}{26 \cdot 18} \times \frac{5}{26 \cdot 65} = 3 \cdot 52 \text{ tons,}$$

$$= \frac{d^4}{l^2}, \text{ or } d^3 = 26 \cdot 65\ \sqrt{3 \cdot 52} = 50;$$

so that the shore must be at least 7 inches square. Also

$$\mathrm{T} = \frac{3 \cdot 635 \times 5 + 27 \times \cdot 75}{26 \cdot 65} = 1 \cdot 442 \text{ tons.}$$

$$\therefore b\ .d^3 = 14 \times 1 \cdot 442\ l^2 = 14{,}333.$$

If $d = 10$ inches, then b should be $14\frac{1}{3}$ inches; or if $d = 11$ inches, then $b = 10 \cdot 8$ inches.

252.—STRUTTING is another kind of shoring, in which the timbers are placed horizontally between two walls, or between the sides of an excavation in the earth, to prevent them from falling towards each other. Flat planks called templates are placed against the surfaces to be

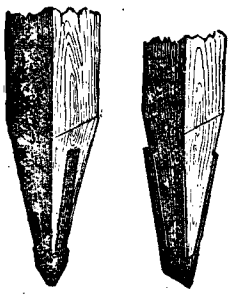
supported, and the strutting is fixed firmly between the templates on each side. If the distance apart is considerable and the pressure likely to bend the struts, they are stiffened with diagonal braces fixed on each side of the struts and abutting against the templates; this arrangement is similar to that shown at A, *fig.* 3, *Plate* XXXVI.

ON THE CONSTRUCTION OF COFFER-DAMS.

253.—A COFFER-DAM is a watertight enclosure or coffer, constructed round the foundations of buildings which are under water, the water being pumped out of the coffer-dam before the building is commenced. A coffer-dam is formed of rows of die-square timbers, called *piles*, pointed at their lower ends and generally shod with iron; these are driven by heavy blows into the bed of the river or other piece of water, as close together as possible, and their interstices filled in with *clay-puddle*. *Guide-piles* are first driven to form the outside, and are placed some few feet apart; these serve as a *guide* to the inner rows of piles. Inside the guide-piles are fixed horizontal beams called *walings*, generally four in number, to keep the inner row from getting out of place, and against these walings the inner piles are driven and bolted to the outer row, the space being filled in with clay-puddle. *Sheet-piling* is formed of piles of whole or half-timber driven very close together, and used as a protection and support in front of a dam of earth.

Piles have an iron ring fixed round their heads to prevent the wood from splitting under the blows of the driver, and are also shod with iron in the manner shown on *figs.* 31 and 32. The form of shoe for single piles is shown by *fig* 31, the point being placed in the centre of the timber. *Fig.* 32 shows the kind of shoe used for sheet-piling, in which they are made with the edge slightly inclined, so as in driving to give the pile a drift towards that last driven, and bring them into the closest possible contact.

FIG. 31. FIG. 32.



Piles from 10 to 14 inches diameter require to be driven with a ram of from 1,000 to 1,700 lbs. weight. Sheet piles 8 or 9 inches wide and 3 or 4 inches thick require a ram of from 500 to 900 lbs. weight. The force of impact will be proportional to the velocity with which the ram strikes the head of the pile, and this varies as the square root of the height through which it falls; thus the same weight falling a height of 16 feet will strike with double the force that it will do if falling only 4 feet.

254.—In order to build the river wall of the Houses of Parliament at Westminster, a coffer-dam was constructed in the river Thames with piles 12 inches square and 36 feet long. The guide-piles were driven 2 feet into the clay under the river bed, after a trench had been first formed by dredging in the line of the dam; their tops rising 4 feet 6 inches above high-water at spring-tides. To these were fixed walings and an outer row of sheet-piling formed of whole timber sawn square, driven close together and bolted to the walings. An inner row of sheet-piling of half-timber was then driven, with similar walings, and within these a row of guide-piles corresponding to the outer row. The outer and inner rows of sheet-pilings were firmly bolted together, and the space between them was filled with stiff clay-puddle. In order to counteract the pressure of the water the dam was strengthened by

counterforts and diagonal bracing introduced between the piling and the old river wall. The section and plan of this structure are shown on *figs.* 33 and 34. The total length of this dam was 920 feet.

FIG. 33.

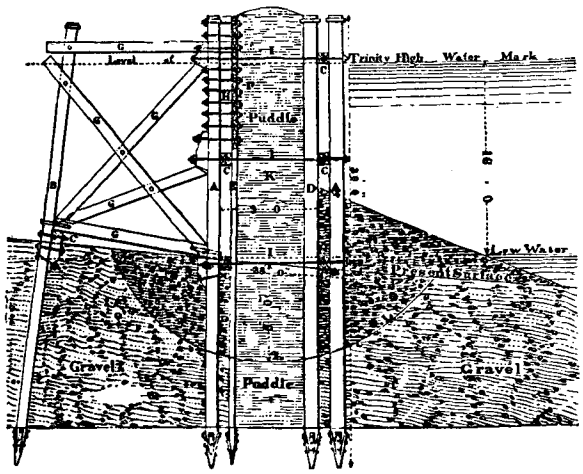
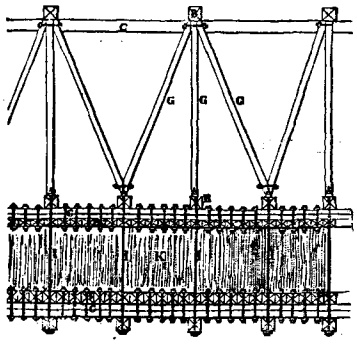


FIG. 34.



255.—For building the piers of London Bridge, coffer-dams elliptical on plan were constructed. The main dam consisted of two rows of piles, leaving a space of 5 feet between each row, with the tops 5 feet above high spring-tides. These piles were connected by means of three rows of double walings secured with 2-inch bolts and wooden cleats $12\frac{1}{2}$ inches square and 3 feet long. A third and outer row of piles was also driven 6 feet beyond the second row, the heads of which were 7 feet below the others. These piles were connected by walings, as above described, and secured to the main dam by iron bolts and wooden cleats. The spaces between the rows were filled with clay, the exterior joints caulked and coated with pitch. All the above-named timbers were of whole timber. Sets of cross and diagonal braces formed of half-timber were used to connect the rows of piling together, and the whole dam was braced longitudinally and transversely with double and single braces of whole timber connected with iron straps and ties. [Much information on the subject of coffer-dams will be found in a treatise on *Foundations*, by E. Dobson. Crosby Lockwood & Co., London.]

SECTION VIII.

ON WOODEN BRIDGES AND VIADUCTS.

256.—The oldest wooden bridge of which we have any account is the Bridge of Sublicius, which existed at Rome in the reign of Ancus Marcius, about 500 years before the Christian era. It owes its celebrity to the combat of Horatius Cocles, a renowned Roman knight who saved the city by a noble defence of this bridge, which it is said was put together without iron or nails.

The next in point of antiquity was that erected by Julius Cæsar for the passage of his army across the Rhine. It is described at some length in his Commentaries; and Alberti, Palladio, Scamozzi, and others, have attempted, from the description, to restore the design; but their representations differ considerably. Cæsar's army passed over this bridge ten days after they began to carry the timber to erect it.

The bridge built by Trajan over the Danube appears also to have been of timber, except the piers, which were of stone; at least, so it is represented in basso-relievo upon Trajan's Column. The roadway of this bridge appears to have been supported by three concentric curved ribs of timber, connected by radial pieces, and is certainly a good specimen of the art of building timber bridges at that early period. Trajan's bridge consisted of twenty or twenty-two stone piers, with wooden arches, each arch above 100 feet span.

257.—In the middle ages, when bridges began to be established on the passages over the principal rivers, they were almost always constructed with piers, at from 15 to 20 feet apart, consisting of one or more rows of piles. These piers were generally defended by a kind of jetta to break the ice, as shown by *fig.* 3, *Plate* XLIV., which also protected the piers from the shock of bodies borne down by the current; nevertheless, in process of time, and from the frequent repairs that were necessary to protect the piers, the water-way generally became almost wholly blocked up; and, consequently, the bridge soon became incapable of sustaining the pressure of water which accumulated in high floods.

The whole of the construction of these bridges was of that kind where abundance of material is made to supply the skill of the artist; yet there are cases where a similar but lighter kind of wooden bridge may be employed with much advantage; that is, in places not subject to floods, or for raising a road across a valley; and, generally, for any situation where the piers can be kept light.

A bridge that was built by Palladio over the Brenta, near Bassano, is a good example of this kind of bridge. (See *Plate* XXXVI., *fig.* 3.) Also the Bridge of St. Clair, on the Rhone,

built by Morand.* In the latter bridge the piers were not constructed in the usual manner, but shorter piles were driven, and cut off a little below low-water mark. On the heads of these piles horizontal pieces were placed, so as to receive the posts to sustain the beams of the roadway, to which these horizontal pieces were secured with straps. As that part of the pier which is alternately wet and dry is subject to very rapid decay, this method renders it easy to repair it without disturbing the lower piles.

258.—Palladio, in his *Treatise on Architecture*, has given several designs for bridges, which display a considerable degree of knowledge of the subject; indeed many of the designs of the present time are merely improvements of the principles exhibited in his valuable work. Palladio appears to have been the first among the moderns who attempted a species of construction that would render numerous piers unnecessary, and so as to avoid exposing any part of the timber work to the shock of bodies carried down by the current. The bridge he erected over the torrent of Cismone, near Bassano, was of this kind, and the span 100 Vicentine feet, or 108 English feet. (See *Plate* XXXVI., *fig.* 1.) One of a very similar construction is shown on *Plate* VIII., *fig.* 2, which represents a truss of a foot-bridge 45 feet span erected over the Farnham and Alton Railway. The platform consists of planking on cross timbers, resting on the tie-beams of two trusses. The upper part of the trusses forms the handrail. Wrought-iron rods $1\frac{1}{2}$ inches diameter are employed where the strain is tensile; the rafters and straining-beam having their ends fixed in cast-iron sockets.

Among the designs for wooden bridges given by Palladio, the most remarkable is that exhibited by *fig.* 2, *Plate* XXXVI.; as it appears to have been the first idea of constructing a system of what may be termed framed *voussoirs*, similar to the arch-stones of a stone bridge; a principle that has since been adopted with much success both in timber and in iron bridges.

259.—Of the modern methods of construction, the best appears to be that of forming curved ribs for the support of the roadway; and this principle seems to have been first applied to bridges by Mr. Price, in his *Treatise on Carpentry*. Mr. Price's method may be stated as follows: He proposes the curved rib to rise about one-sixth of the opening, and to divide it into a convenient number of equal parts, according to the span, or to suit the lengths of the timber. For a bridge of 36 feet span, he proposes to make the ribs of pieces of oak in five lengths, and 3 inches in thickness; each rib to consist of two thicknesses, one 12 inches deep, and the other 9 inches deep; the joints crossed, and the thicknesses keyed together with wooden keys. Two of these ribs with joists framed between, he says, will be sufficient to support the roadway.

Since the publication of Price's work, this method of construction has been brought to considerable perfection in Germany and other places on the Continent, and in America. The following particulars respecting some of the most celebrated wooden bridges cannot fail of being interesting to the reader.

AMERICAN BRIDGES.

260.—The famous wooden arch of 250 feet span, across Portsmouth River, in North America, was put together with wooden keys similar to those proposed by Mr. Price; indeed it

* Gauthey, tome ii.

is precisely his method of construction applied to a larger span, excepting a little difference in the form of the keys. The arch was built by Mr. Bludget, and is described by Colonel Sir Howard Douglas, Bart., in his work on Military Bridges, who brought from America an accurate drawing of this ingenious structure.

The arch was composed of three concentric arcs, ABC, DEF, GHI (*fig.* 4, *Plate* XXXVI.), of which that in the centre, DEF, and the corresponding arches on the other two sets, supported the floor of the bridge. The circular beams, ABC, DEF, GHI, were connected with each other by pieces of hard wood *a c*, *a c*, and a wedge *b* (*fig.* 5) at the parts 1, 2, 3, 4, &c. (*fig.* 4), where corresponding mortises were prepared. The wedge secures these triple tenons in their mortises, and connects the centre beam, AB, *fig.* 5 (DEF, *fig.* 4), with the other two beams, by the dovetail tenons at the extremities of the keys, *a c*, *a c*. Each circular beam or arc, ABC, *fig.* 4, was composed of pieces of timber about 12 or 15 feet long, fastened together by dovetail keys and wedges. The joining D of every two beams, A, B, *fig.* 6, was in the centre of the opposite beam C (breaking joint, as it is termed). Mortises, wider on the outside than on the inside, were cut in the half-beams or pieces, A, B, C, *fig.* 6; so that when they were laid together, the mortises formed a double dovetail cell, *fig.* 7, admitting of two pieces of hard wood, *c*, *c*, which were fastened in by the wedge *d*.

Sir H. Douglas observes, that the arch is extremely flexible, and that diagonal braces would be an improvement. Also, if the three ribs had been placed close above one another, and firmly connected together, the bridge would have been much stronger to resist any unequal load; as they would then have formed a solid beam equal in depth to the sum of their depths. But it would have been still better to have made the same quantity of timber into two ribs with cross ties, and diagonal braces between them. The manner of connecting the parts by means of dovetail keys is not a good one, as the timber must be much weakened by mortises so large as they require, and a very slight degree of shrinkage renders them useless. (See Section IX., Art. 307.) And it is still more objectionable as applied to the radial pieces, 1, 2, 3, 4, &c., *fig.* 89. These pieces would be much better notched on in pairs, and bolted through.

261.—Plate XLI. is a drawing of "Town's Patent Lattice Bridge," which was much employed on the early American railways. This construction is sometimes used for bridges of so large a span as 150 feet, and it exerts no lateral thrust tending to overturn the piers on which it rests. A small quantity of materials of very small scantling, arranged in the manner shown in the plate, possesses a great degree of strength and rigidity.

Mr. Robinson, of Philadelphia, constructed many large bridges on this principle on the Philadelphia and Reading Railway. (See *Civil Engineering in North America*, by D. Stevenson.)

Fig. 1 is an elevation, and *fig.* 2 a cross section on an enlarged scale of the framework of the bridge, in which *a* is the surface of the railway; the lattice framing or ribs *b* of which the bridge is formed were composed entirely of pine planks, measuring 12 inches in breadth, and 3 inches in thickness. The planks were arranged at right angles to each other, so as to form a fabric resembling lattice work, as shown in the drawing; and from this circumstance the bridge derived its name. They were fixed at the points of their intersection by oak treenails, $1\frac{1}{2}$ inches in diameter, passing through them. The horizontal runners, *c*, were formed of planks of the same scantling, and extend throughout the whole length of the bridge.

They were also fixed at the points where they intersected the planks *b*, by oak treenails passing through the whole, as shown by the dotted lines at *f* in *fig.* 2. The depth of the lattice-work was proportioned to the span of the bridge. The span shown in the drawing is 78 feet, and the depth of the ribs is 9 feet 6 inches. In a bridge of larger span, the planks *b* would be made of greater length, and another square or diamond added to the lattice-work.

Two ribs or frames of lattice-work were used in the bridges constructed on this principle. One of these was placed under each side of the roadway, as shown in the cross section, *fig.* 2, by the letters *b b*. The ribs were connected together at the bottom by cross-beams *e*, at every 12 feet. At the top they were connected in a similar manner by beams *d*, at every 6 feet. On these the longitudinal beams *g* were supported, to which the planking of the roadway was spiked. To prevent the ribs from twisting or warping, they were braced at every 12 feet by diagonal beams arranged in vertical planes, as shown at *h* in *fig.* 2. *Fig.* 3 is a plan of the wood-work directly under the roadway. In this figure the beams *d* are those on which the planking of the roadway was spiked, and the diagonal braces *m* arranged in horizontal planes were introduced to render the structure rigid. For the same reason the braces *i* were introduced, as shown in *fig.* 4, which is a plan of the wood-work connecting the lower part of the lattice-frames. The diagonal braces were all fixed in the same manner. One of the extremities rested in a seat cut for it in the beam against which it abutted, and wedges of hard wood were inserted at the other end, by which the brace could be nicely adjusted, and afterwards tightened up, should the vibration of passing trains, or the effects of the atmosphere, cause any yielding of the timber to take place.

The lattice-frames had a rest of about 5 feet, in checks formed in the stone abutments for their reception, as shown in dotted lines in the elevation *fig.* 1 and in *fig.* 5, which is a plan of one of the abutments. If the bridge were of greater extent than could be included in one span, it was simply rested on a thin pier, in the manner shown in the elevation, without any other support. A covering of light boarding, extending from the level of the roadway to the bottom of the ribs, was spiked on the outside of the lattice-work to preserve the timber.

The largest lattice-bridge which was constructed by Mr. Robinson on the Philadelphia and Reading Railroad measured 1,100 feet in length. The lattice-frames of which it was formed extended throughout the whole distance between the two abutments without a break, and were supported on ten stone piers, in the manner shown in the plate. On the New York and Haerlem Railway there was a lattice-bridge 736 feet in length, supported in the same manner on four stone piers.

262.—Long's patent frame bridge was also much employed on the different lines of railway in the United States; it contains a small quantity of materials, and exerts no lateral thrust. Bridges constructed on this principle, having spans of from 100 to 150 feet, were very commonly met with. The string-pieces were formed of three beams. The post and main-braces were in two pieces, and the counter-braces were formed of a single beam. The joining was effected without the use of bolts or spikes, a construction which admitted of the bridge being very easily repaired, when decay of the materials or other causes renders it necessary. An illustration of Long's bridge will be found in Stevenson's *Civil Engineering in North America.*

The timbers of which Town's and Long's bridges were composed, were fitted together on the ground previous to their erection on the piers. They were again taken asunder, and each

beam put up separately in the place which it was to occupy, by means of a scaffolding or centering of timber.

These lattice-bridges were found to answer very well for ordinary roads, but not for the heavy traffic of railways, owing to the number of joints and the shrinking of the timber, which caused settlements to take place. The strains to which they were subjected caused the joints of the chords to tear asunder, the lattice pieces to split, and the top to buckle. When, however, they were strengthened by arched ribs, as shown on *Plate* XXXVIII, they were found to answer admirably.

263.—The HOWE bridge was an improvement on the LONG bridge, in having vertical tie-rods of iron instead of the wooden posts, and by these the bridge could be cambered. The panels were from 10 to 11 feet wide, and there were four bottom chords on each side, 40 to 44 feet long, the scantling of each being $6'' \times 12''$, and extending over four panels with only one joint in the chord pieces in any one panel. Oak splicing pieces 6 feet long were inserted at every joint, and oak keys $12'' \times 2\frac{1}{2}''$ were let in $\frac{3}{4}''$ between each chord piece at intervals of 5 feet, the whole of the chords being bolted together by numerous bolts to keep them from stretching. Rigidity was imparted by keying up the counter-braces; the main-braces increasing from the centre to the abutments; angle blocks were fixed at top and bottom of the braces, either of oak or cast-iron; the vertical wrought-iron rods were from $1\frac{1}{4}''$ to $1\frac{3}{4}''$ diameter. The transverse joists $6'' \times 12''$ rested on the bottom chords, 2′ 9″ apart, and on these were placed the longitudinal pieces for the rails. One of these bridges, erected at Richmond to carry a railway over the James River, was 1,800 feet long, and had eleven spans of 121 feet; the depth of the truss was 20 feet, and the width 18 feet. It was formed of two trusses, the upper chords consisting of two pieces $9'' \times 12''$ and four pieces $5'' \times 9''$; the bottom chords of four pieces $6'' \times 12''$ and four pieces $5'' \times 12''$; the area of the section of the top chord being 396″ and of the bottom chord 528″, the latter always being made stronger than the former on account of the numerous joints. The braces were $8'' \times 9''$ and $7\frac{1}{2}'' \times 7''$, the iron tie-rods being $1\frac{5}{8}''$ and $1\frac{1}{2}''$. These bridges were always built of the best white pine, and required about 30 cubic feet of timber to every lineal foot. The calculated compressive strain on the upper chords was 729 lbs. per square inch of section, and on the end braces 735 lbs. The tension on the bottom chords was 547 lbs., and on the iron tie-rods 15,125 lbs. (See a paper on *American Timber Bridges*, by J. R. Mosse, in the Proceedings of the Institute of Civil Engineers, 1863.) A bridge of this kind erected on the Portland railway had arches of 150 feet span, the trusses being 19 feet high; the calculated strains per square inch were about one-fourth more than those given above.

264.—An improvement upon the HOWE truss was effected in the case of bridges which had to bear a heavy railway traffic, by introducing an arch on each side of the truss. A bridge erected on the Philadelphia and Reading line had a span of 160 feet, and consisted of three trusses 23 feet deep, so that there were six arches which were of best pine in pieces 24 feet long, $4\frac{1}{4}''$ wide, and 15″ deep, four to each arch breaking joint every 6 feet. The total sectional area of the arches was 1,530″, of the upper chords 1,215″, and of the bottom chords 1,620″. The main-braces were $8'' \times 10''$, the counter-braces $8'' \times 8''$; the width of each panel was 10′ 3,″ the iron tie-rods being $1\frac{5}{8}''$.

Another bridge on this principle over the Delaware had a span of 260 feet. Bridges with arched top were also erected for several railways, 200 feet span, having a depth

of 26 feet at the centre, and 21 feet at the ends; the sectional area of top being 814″, and of the bottom 468″.

265.—The bridge over the river Delaware, at Trenton, about thirty miles from Philadelphia, consisted of five wooden arches, three of 200, one of 180, and one of 160 feet span, supported on four stone piers. It is illustrated in Stevenson's *Civil Engineering in North America.** The roadway of each span or opening was suspended by iron rods, from five wooden arcs, on the same principle as the iron bridge over the river Aire at Leeds in Yorkshire. The wooden arcs in the three largest openings were 200 feet in span, and had a versed sine of 27 feet. The arcs and suspending rods divided the roadway into four compartments, forming two carriage-ways in the middle of the bridge, each of which was 9 feet 10 inches in the clear, and a footpath at each side 4 feet 10 inches in the clear. The entire breadth of the bridge, measured over the outer suspending arcs, was 33 feet 8 inches. The whole was covered with a roof.

The suspending arcs abutted against strong oak planks, which extended throughout the whole breadth of the stone piers. They were supported at each pier by struts and connected at the top by a series of diagonal beams; these extended only about half-way down the arcs on each side of the crown, so as not to interfere with the height of the roadway. The suspending arcs were composed of eight thicknesses of pine plank, and measured 2 feet 8 inches in depth, and 1 foot 1 inch in breadth. The planks of which they were made measured 1 foot 1 inch in breadth, 4 inches in thickness, and from 30 to 50 feet in length, and were arranged so as to break joint. The wooden braces were for the purpose of stiffening the roadway. They were fixed to the suspending arcs, and to the longitudinal bearing beams of the roadway by straps of iron. The suspending rods were formed of malleable iron, every 16 feet in the two exterior arcs, and at every 8 feet in the three inner ones, which support the carriage-way.

266.—The bridge over the Susquehanna, at Columbia, was constructed somewhat on the same principle as the one at Trenton, just described. The wooden suspending arcs, however, did not spring from the level of the roadway, but from a point about 8 feet below it. In each span of the bridge, therefore, that part of the roadway next the springings was supported upon the arcs; and the centre part of it suspended from them by a framing of wood. This bridge, which was begun in 1832, and completed in 1834, consisted of no fewer than twenty-nine arches of 200 feet span, supported on two abutments, and twenty-eight piers of masonry founded on rock, at an average depth of 6 feet below the surface of the water. The waterway of the bridge was 5,800 feet; and its whole length, including piers and abutments, about one mile and a quarter. The bridge was supported by three wooden arcs, forming a double roadway, adapted for the passage both of road and railway carriages. There were also two footpaths; which made the whole breadth of the bridge 30 feet. The arcs were formed in two pieces, each measuring 7 inches broad by 14 inches in depth, placed 9 inches asunder; and the beams composing the wooden framing, by which the roadway was suspended, were placed between them, and fixed by iron bolts passing through the whole.

267.—The Market Street Bridge over the Schuylkill, at Philadelphia, consisted of three arches. The span of the centre arch was 194 feet 10 inches, and the versed sine 12 feet. The other two arches were 150 feet in span, and had versed sines of 10 feet. The breadth

* Crosby Lockwood & Co.

of the roadway was 35 feet. The piers were built with coffer-dams, one of them at the depth of 41, and the other at the depth of 21 feet below the surface of the river at high water. The work was commenced in 1801, and completed in 1805. There was another bridge over the Schuylkill at Philadelphia, consisting of a single arch of no less than 320 feet span, having a versed sine of about 38 feet. This bridge had a breadth of roadway of about 30 feet. After it had stood for several years in good repair and constant use, it was destroyed by fire. Both these bridges are illustrated in Stevenson's *Civil Engineering in North America.*

SCHAFFHAUSEN BRIDGE.

268.—In Switzerland several excellent wooden bridges have been erected; one of the most celebrated was that of Schaffhausen, constructed in 1757, by John Ulrich Grubenmann, a village carpenter of Tuffen, in the canton of Appenzel, but certainly one of no ordinary capacity. It was composed of two arches, the one 172 feet, the other 193 feet span, supported by abutments at the ends, and by a stone pier in the middle, which remained when the stone bridge was swept away in 1754. In this bridge the oak beams which rested upon the masonry of the abutments and pier not having been sufficiently seasoned, nor raised from the stone-work so as to admit a circulation of air round them, rotted, and the frames began to settle. Grubenmann being dead, a carpenter of Schaffhausen, named Georges Spengler, undertook to remedy the defect in 1783. He raised the whole bridge by means of screw-jacks upon scaffolding, supported by piles; and replaced the decayed timbers by others of a better quality. This was the only repair that was done to it during the forty-two years it existed; it was burnt by the French army in 1799.

The construction is ingenious, and the principle is shown in *fig.* 4, *Plate* XXXVIII. (See Art. 289.) It has been remarked, as the most essential defect, that all the principal supports are so dependent upon one another, that a single part cannot be removed without first supporting the whole bridge. For further particulars relating to this structure, the reader is referred to the plate and description published by the late Mr. Taylor; but it is necessary to state, that this bridge, in common with others constructed on the same principle, bent considerably sideways.

Schaffhausen Bridge was finished in less than three years: and it is said that a man of the slightest weight felt it almost tremble under him, yet waggons heavily laden passed over it without danger. It is often stated that the middle pier was not necessary as a support to it; this, however, is a mistake, as it certainly would not have borne its own weight without the assistance of the middle pier.*

FREYSINGEN BRIDGE.

269.—The construction of bridges with curved ribs has been much employed by Wiebeking. Instead of forming the ribs of short lengths, he employs pieces of considerable length, and bends them to the form of the curve. This method has many

* Rondelet's *L'Art de Bâtir.* Gauthey's *Construction des Ponts.*

advantages over that in which short pieces are used; it lessens the number of joints, consequently the ribs are more firm, and less liable to decay. The bridge of Freysingen, on the Isar in Bavaria, is one that was constructed according to Mr. Wiebeking's method, in the years 1807 and 1808. It consisted of two arches of 153 feet span, with a rise of 11·6 feet; and the width of the roadway was 25 feet. (See *Plate* XXXVII., *figs.* 1 and 2.)

The ribs which supported the roadway consisted of two parts, the one more curved than the other; that which was most curved was built with three courses of beams, of from 12·6 to 14·5 inches in thickness, and about 46 feet in length. Each beam having been bent to the proper curve by screws or levers, and scarfed and bolted to the rest. The upper part of the rib consisted of only two courses of beams of 15·5 inches each.

Each of the abutments was 21·25 feet in thickness, and rested upon 68 piles. The piles were from 30 to 38 feet long, and 15·5 inches square; and they were driven from 17·4 to 19·4 feet into the ground, with a ram of 1,486 lbs. weight. The straighter parts of the curved ribs abutted against five piles which were driven within about 3 feet of the back of the abutment; these piles were 12·6 inches square, and had 20 feet hold of the ground, and were also further strengthened by building the abutment round them. In the elevation of the bridge, *fig.* 1, the abutment to the left of the figure is supposed to be cut through, to show how the two parts of the rib abut into it.

Each arch consisted of three curved ribs, which were bonded together at seven places, by cross-ties, each consisting of several pieces of timber laid one upon another: and these ties supported seven ranges of beams, laid in the direction of the length of the bridge, with diagonal braces between them, and the joisting of the roadway laid across them.

In the spaces between the springing of the arches and the first cross-tie, inclined braces were fixed crossing one another, and similar braces were fixed between the cross-ties on each side of the crown of the arch, serving to strengthen the bridge against any lateral strain. The upper part of the ribs was continued into the abutments for the same purpose.

The pier, which sustained the arches in the middle, consisted of nine vertical piles of 17·5 inches diameter, driven about 17·5 feet into the bed of the river; and two inclined piles about 46 feet long. The base of the pier was surrounded by a bed of large gravel stones, with the joints filled with water cement. The ends of the ribs abutted into vertical posts, which rested upon horizontal sills, that were secured to the piles by bolts and straps. A lining of strong oak planking was placed between the vertical posts and the piles, and the spaces formed between the planking and the piles were filled with beton, or concrete. *Fig.* 2 is a section across the bridge close to the pier.

In order to preserve the timbers, the mortises and tenons of the vertical posts were soaked in hot oil; and small gutters were made near the lower ends of the curved ribs and braces to cause the water to run off, instead of settling into the joints. To all the principal timbers two coats of pitch and tar were applied.

The exterior of the bridge was covered with boarding, painted, and dark lines drawn for the joints, so as to imitate a stone bridge. (See the part of the elevation to the right, in *fig.* 1.) The simple inspection of the figure must convince any one that a stone bridge could not be executed with so slight a pier; consequently the bridge must have always appeared what it really was. An attempt at deception, ill managed, is always regarded with contempt; and it is much to be regretted that some of the finest specimens of this artist's skill are hid beneath a

clumsy imitation of stone-work; whereas, had they appeared without this disguise, they would have drawn forth the praises of every one. It may be stated in favour of covering wooden bridges with boarding, that it assists in preserving them; but of this there appears some doubt, as it will retain damp air round the timbers, and cause them to decay perhaps sooner than when exposed to free evaporation.

The arches did not settle regularly in this bridge; the one settled only about 3·4 inches, while the other settled 11·6 inches, and in the manner shown in the dotted line upon the elevation, *fig.* 1. The cause of this irregularity seems to be the want of attention in making the beams regular; consequently, the forces they would exert to regain their original form not being equal, the arch would bulge in the weakest place.

This bridge was entirely destroyed in the campaign of 1809; but has been since rebuilt nearly on the same plan.

THE BRIDGES OF BAMBERG AND ETTRINGEN.

270.—The Bridge of Bamberg, on the Regnitz, in Germany, is another example of Wiebeking's methods of construction; the widest span that has been executed according to his principle. It was built in 1809.

It consists of one arch of 208 feet span, with a rise of 16·9 feet, and the width of the roadway is 32 feet. (See *Plate* XXXVII., *figs.* 3 and 4.) A stone bridge had formerly been erected on the same site; but its heavy piers contracted the water-way so much, that the water in a flood accumulated to such a height as to overturn the bridge by its pressure. In consequence of this accident the wooden bridge was made to span the whole width of the river.

In the middle of the width of the bridge, three ribs are placed side by side, the middle one being five beams in depth at the abutments, but only three in depth at the crown: but the ones on each side of it are three beams in depth throughout. On each side of the bridge there are two ribs placed side by side, and bolted together; each of these consists of five beams in depth towards the abutment, and three beams in depth at the crown. The depth of the beams is from 13·5 to 15·5 inches. The three compound ribs are united together by cross-ties, with diagonal stays or braces between, as in the Freysingen Bridge; also the roadway is constructed in the same manner.

In the elevation, *fig.* 3, the boarding is supposed to be removed from one-half of the bridge, and the abutment cut through, to show the manner of framing the timbers. *Fig.* 4 is a section across the bridge at AA on the elevation, to a larger scale.

The joints of all the parts built into the abutments were well soaked in hot oil, and also covered with sheet lead. The ribs and joists are of fir, the cross-ties and plates of oak.*

In a bridge constructed near Ettringen, by Wiebeking, of which the span was 139 feet, and the rise 8 feet, a different method of strengthening it against lateral motion was adopted. Two ribs were placed parallel to each other at the sides of the bridge, and other two ribs were placed diagonally between them, so as to cross each other in the centre of the bridge.* This method of placing the ribs rendered braces in the flooring unnecessary.

* Wiebeking's *Traite d'une Partie Essentielle de la Science de construire les Ponts.*

Some very light and elegant wooden bridges have been erected by Mr. James Burn, of Haddington; the largest is over the river Don, seven miles from Aberdeen. The span of this bridge is 109 feet 3 inches, the rise 13 feet 4 inches, the radius of curvature 119 feet, and the width of the roadway 18 feet.*

To supply, in some measure, the place of further descriptions of the various kinds of bridges that have been executed, we have, in Arts. 288 to 294, considered the leading principles of construction; which, with the following tables, will materially assist in informing the reader what has been done, and consequently enable him to see how far the art is capable of improvement.

271.—*A Table of the principal Dimensions of the Bridges constructed by Wiebeking, with Curved Ribs.*†

Name, situation, and date of finishing.	Width of roadway in feet.	Span of the arches in feet.	Rise of the arches in feet.	Radius of curvature in feet.	Span to a rise of unity.	Longest lengths of beams in the ribs in feet.	Depth of beams in the ribs in inches.	The deflection being 1, the length of the beam was	Distance of cross-tie in feet.
Bridge of Bamberg, on the Regnitz, 1809	32	208	16·9	422	12·5	53	13·5 to 15·5	50·8	13
Bridge of Shärding, on the Rott, 1809 ...	25	194	18·8	258	10·26	62	12·6 „ 15·5	37·14	16
Bridge of Freysingen, on the Isar, 1808 ...	25	153	11·6	246	13·25	46	12·6 „ 14·5	32	19·3
Bridge of Augsbourg, on the Lech, 1808 ...	$25\frac{1}{6}$	114	10·6	158	10·72	41	12·6 „ 14·5	23·28	18·8
Bridge of Ettringen, over the Wertach, 1809	25	139	8	305	17·46	46	12·6 „ 15·5	26·2	11·6
Diagonal ribs of ditto ...	...	144	8	355	18	...	...	...	...
Bridge of Irsingen, over the Wertash, 1808	25	126	7	285	17·91	48	11·6 „ 14·5	30	15·5
Bridge of Oettingen, over the Inn, 1807	25	103	6·8	200	15·29	59	13·5 „ 15·5	24·4	17·4
Bridge of Vilshoven, on the Vils, 1809 ...	27	179	11·1	378	16·09	38	13·5 „ 15·5	30	11·6
Bridge of Altenmarkt, on the Alz, 1809	27	140	12·9	203	10·96	38	9·68	30	7·9

* *Edinburgh Encyclopædia*, Art. "Bridge."

† From Wiebeking's *Traite d'une Partie Essentielle de la Science de construire les Ponts.*

272.—*Table of the Spans of some of the most celebrated Wooden Bridges in Europe.*

Name, date, and situation.	Width of roadway.	Span of widest opening.	Rise of widest opening.	Authority.
Bridge of Schaffhausen, 1757, by Ulrich Grubenmann, two arches	...	172 193	...	Cox's *Travels.*
Bridge of Kandel, in the Canton of Berne, 1764, by Ritter, constructed of fir ...	16	166	...	Rondelet, *L' Art de Bâtir.*
Bridge of Walton-upon the Tahmes, by Etheridge, about 1758	...	130	27	Smeaton's Reports, vol. iii, p. 371.
Bridge of Zurich	...	125	...	Gauthey.
Bridge of Landsberg, over the Lech, 1807, by Wiebeking, of fir	22¼	123	...	Wiebeking.
Bridge of Sault, on the Rhone, France ...	...	110·8	...	This bridge failed in a few years. See Art. 289. Gauthey.
Bridge over the Don, seven miles from Aberdeen, 1803, by James Burn ...	18	109¼	13⅓	Telford: *Edinburgh Encyclopædia.*
Bridge of Cismone, by Palladio	...	108	...	Rondelet.
Bridge of La Cité on the Seine, Paris, 1802, by Demoutier, of oak	34	104	...	Gauthey.
Bridge of Seurre, on the Saone	...	94	...	Gauthey.
Bridge of Tournus, on the Saone, 1801, by Gauthey, of oak	31½	89½	...	Gauthey.
Bridge of Granholm, four miles from Aberdeen, by James Burn...	10½	71½	10½	Telford: *Edinburgh Encyclopædia.*
Bridge of Choisy, on the Seine, 1811... ...	...	67	9	Gauthey.
Bridge of Chazey, on the Ain	21	64	...	Gauthey.
Bridge of Brechin, by James Burn	15	58	10	Telford: *Edinburgh Encyclopædia.*
Bridge of Mulatière, Lyons, on the Saone, by Lallié	31½	57	...	Gauthey.
Bridge of St. Clair, on the Rhone, by Morand, 1775...	42½	45	...	Gauthey.
Bridge of Bassano, over the Brenta, by Palladio	27	36·8	...	Rondelet.

ON THE DESIGN OF WOODEN BRIDGES.

273.—The principal objects to be attended to in a design for a wooden bridge are, 1st, the choice of a proper situation; 2ndly, the width of the roadway; 3rdly, the water-way which ought to be left for the river; and 4thly, the span of the arches. Each of these is chiefly determined by local circumstances.

The principal object in erecting a bridge is to obtain a more easy and ready communication between the opposite banks of a river, a deep ravine, and places of a like nature; and, in general, the situation ought to be that which is most convenient for the use of the public. Sometimes, however, it happens that the most convenient situation is not the best adapted for the erection of a bridge. In this case the advantages and disadvantages of other situations

should be carefully considered, and the site determined, so that the means of communication may be as direct as possible, and the access to the bridge commodious.

This determination will be much facilitated by making a correct plan of the course of the river, and of the roads which are to be connected with the bridge. This plan should be sufficiently extensive to give a correct idea of the nature of the river, and of the changes its bed may have undergone; and also of the directions of the roads.

The bridge should always, if possible, cross the stream at right angles; and it is an advantage, when the course of the river is nearly straight for a considerable distance above the bridge; and when there is a contraction in the channel at a little distance below the bridge, it renders the effects of floods less dangerous.

The situation being fixed upon, a correct section should be made of the bed of the river showing the form of the opposite banks, and the depth of water at different seasons of the year. Also on this section should be put the line of the highest and lowest water marks, which should be drawn from the best information to be procured from the observations of the oldest inhabitants of the neighbourhood.

The nature of the bed of the river should be carefully examined, particularly in the site of the abutments or piers, by boring, driving in a rod of iron, or other means, to a sufficient depth to be certain of the quality of the ground.

It would also be desirable to have a section showing the declivity of the bed of the river for a considerable distance above and below the situation of the intended bridge, and also the velocity of the stream at different periods.

THE WIDTH OF THE ROADWAY.

274.—The width of a bridge depends wholly on the situation of the place where it is to be erected. It ought to be wide in proportion to the importance of the communication to be effected, and according to the population of the place at or near where it is situated; but it is desirable that its width should not be greater than its situation requires, because it increases the expense of erection without adding to its utility.

The width of a bridge between the parapets, intended for wheeled carriages, may be from 18 to 45 feet, according to the situation. Where the road is at a distance from any principal town and has little traffic upon it the width of the bridge may be from 18 to 20 feet; in more frequented places, from 20 to 22 feet; near to towns and on great public roads, from 25 to 30 feet; and in or near large cities, from 30 to 45 feet.

In private roads and parks they are made from 12 to 20 feet in width, and foot-bridges from 5 to 8 feet.

ON THE WATER-WAY LEFT FOR THE RIVER.

275.—The water-way of a bridge should be sufficient to give free passage to the highest floods, and particular regard must be had to this circumstance in fixing the height and width of the arches.

The form and quantity of water-way is often so much altered by the bulk of the piers that there is an increase of velocity in the current under the bridge; and when the bottom is of such a nature that it will yield to this increased action of the current, there is much danger of the bases of the piers being undermined; also in navigable rivers it renders the navigation difficult and often dangerous. Whereas, if the forms and magnitudes of the piers be so contrived that there shall be only a very small increase of velocity under the bridge, those evils will be avoided, and the floods will pass without doing any material injury.

Whenever the velocity is increased by contracting the width of the stream, the bottom wears deeper, unless it be so hard as to resist the increased action of the current. In the latter case the chief evil will be the fall of water under the arch.

The velocity of rivers is extremely variable; it depends chiefly on the declivity of the bed, and is most considerable in mountainous countries. In level districts there is little to be apprehended from the effect of the velocity; nevertheless it would not be prudent, even in level situations, to contract the water-way so as to produce a rapid fall under the bridge, particularly if the bed of the river be not sufficiently firm to withstand it.

The danger of a considerable fall under the bridge is well known from the bad construction of the old London Bridge, where the fall during the ebb was generally about 4 feet; and many lives have been lost in attempting to pass it. The want of a sufficient water-way appears to have been one of the causes, if not the chief cause, of the failure of Hexham Bridge, in which the fall was not less than 5 feet at the time the bridge fell,* and the bottom not of a nature to withstand such an increase of velocity.

A bridge seldom if ever fails unless in consequence of a want of water-way; and, on the other hand, care should be taken not to run into the other extreme, as it is equally dangerous; because, when more space is left than is necessary, a deposit takes place of sand and gravel, which, when once begun, in process of time reduces the water-way so much as not to allow a free passage to floods.

276.—The following table will enable the reader to compare the firmness of bottoms of different materials. The experiments were made by Dubuat.† The second column gives the greatest velocity the material in the third column is capable of resisting; and the fourth column contains the specific gravity of the material. In the first column the popular stages of accumulation are stated.

Stages of accumulation termed.	Velocity of river in feet per second.	Nature of the bottom which just bears such velocities.	Specific gravity of the material.
Ordinary floods ...	3·2	Angular stones, the size of a hen's egg ...	2·25
	2·17	Rounded pebbles, one inch in diameter ...	2·614
Uniform tenors ...	1·07	Gravel of the size of garden beans	2·545
	0·62	Gravel of the size of peas	2·545
	0·71	Coarse yellow sand	2·36
Gliding	0·351	Sand, the grains of the size of aniseeds ...	2·545
Dull...	0·26	Brown potter's clay	2·64

* Smeaton's *Reports*. It appears that the bottom was sufficient to withstand a fall of 3 feet 9 inches, but failed in the flood which rose to 5 feet.

† *Principes d'Hydraulique*.

277.—It appears, then, that the velocity of the water under the bridge is determined either by the nature of the bed of the river or by the quantity of fall that would be hurtful to navigation.

If b represent the breadth of the natural water-way, and c the breadth as reduced by the construction of the bridge; also V the velocity in feet per second of the river in its natural state; then the velocity v under the bridge will be expressed by the equation $v = m \cdot \mathrm{V}\frac{b}{c}$, and $c = m \cdot b\frac{\mathrm{V}}{v}$. Where m is a constant quantity which expresses the contraction a fluid suffers in passing through a narrow passage. According to Sir Isaac Newton's experiments, the value of m is $\frac{25}{21}$;* this value of m should be used when the ends of the piers are square; but they are generally made of a form better adapted for dividing the stream; and Dubuat has made some experiments with models of piers with the end facing the stream in the form of an equilateral triangle, and according to these experiments we may take $m = 1{\cdot}09$.† Adopting this value, $v = 1{\cdot}09\ \mathrm{V}\frac{b}{c}$, and $c = 1{\cdot}09\ b\frac{\mathrm{V}}{v}$.

Example. Let the bottom of the river be fine sand and the breadth of the natural water-way 36 feet, and the velocity $\mathrm{V} = 0{\cdot}25$ feet per second. Then for a fine sandy bottom, v should not exceed 0·351 feet; hence $c = 1{\cdot}09\ b\frac{\mathrm{V}}{v} = \frac{1{\cdot}09 \times 36 \times 0{\cdot}25}{0{\cdot}351} = 27{\cdot}9$ nearly, which is the breadth of the contracted water-way; and 8·3 feet may be occupied with piers without endangering the bottom.

Retaining the same notation, the quantity of fall, h, will be found by the equation, $\frac{m^2 b^2 - c^2}{64 c^2} \times \mathrm{V}^2 = h$.‡ And taking the value of $m = 1{\cdot}09$, then $m^2 = 1{\cdot}1881$; or near enough for practice, $m^2 = 1{\cdot}2$; consequently, $\frac{1{\cdot}2 b^2 - c^2}{64 c^2} \times \mathrm{V}^2 = h$, the fall.

Example. The breadth of the Thames above London Bridge was about 936 feet, according to the observations of Mr. Labelye, in 1746; and the sum of the water-ways of the old bridge at the time of low water was about 200 feet; the mean velocity of the stream just above the bridge $3\frac{1}{6}$ feet per second. Therefore, $\frac{1{\cdot}2 b^2 - c^2}{64 c^2} \times \mathrm{V}^2 = \frac{1{\cdot}2 \times 876096 - 40000}{64 \times 40000} \times \frac{361}{36} = \frac{1011315{\cdot}2}{2560000} \times \frac{361}{36}$ = 3·96 feet, or 4 feet nearly, which rendered the passage extremely dangerous.

The velocity of the current and the area of the section of the water-way should be ascertained at the time of the highest floods; but as this is seldom possible we must often be satisfied with an approximate value of the fall at that time; which may be obtained by observing the velocity when the river is as much above its ordinary height as it may happen to be during the time allotted for observation, and ascertain the depth of the river corresponding to that velocity. Now in the same river and situation the velocity is nearly as the square root of the depth; therefore the velocity for one depth being known, that for any other depth may be found by direct proportion.§

* *Principles of Natural Philosophy.*

† Dubuat's lowest number is 1·097, but in wide rivers perhaps it will be less; therefore we have assumed 1·09 as near the truth. See Dubuat's *Principes d'Hydraulique.*

‡ An investigation on this formula is given by Dr. C. Hutton, in his *Tracts;* also in his *Course of Mathematics.*

§ See *Hydraulic Tracts*, where more accurate formulæ for the motion of water in rivers are given.

The fall under the bridge is directly as the square of the velocity, therefore there is much danger in contracting the water-way of a rapid river, and the fall will also be nearly as the depth of the river; which shows how necessary it is to ascertain the height of the highest floods.*

278.—The following is a table showing the velocities of some of the principal rivers, which may assist in giving more accurate ideas on this interesting subject:—

Name of river.	Place of observation.	State of river.	Velocity in feet per second.	Observer.
Thames ...	Above London Bridge	Mean state ...	3 ·1667	Labelye.
	Above Westminster Bridge ...	Mean state ...	2 ·25	Labelye.
Seine ...	Between Tuileries and Pont-Neuf	...	1 ·54	Mariotte.
	Between Surenne and Neuilly ...	...	2 ·55	Chesey.
Tiber ...	Rome	Low water ...	3 ·28	...
Danube ...	Ebersdorf	Low water ...	3 ·45	...
		High water...	from 7 ·2 to 12 ·2	...
Loire ...	... ...	...	4 ·25	...
Rhone ...	At Arles	Low water ...	4 ·8	...
	At Beaucaire	Low water ...	8 ·2	...
Durance ...	From Sisteron to its mouth ...	Mean state ...	8 ·2	...

In 1818 an immense quantity of water was collected in the Val de Bagnes, in Switzerland, by a glacier sliding into the valley; when the ice gave way the torrent burst forth with the tremendous velocity of 33 feet per second, and swept two bridges away in its course, and still retained a velocity of 6 feet per second when it flowed into the Lake of Geneva, a distance of nearly five miles.†

OF THE SPAN OF THE ARCHES.

279.—The extent of the span is the next subject to be considered; it will de obvious that this is in some degree determined by what has been said respecting the quantity of water-way. The span of the arch, however, must also be regulated by the form of the banks, the height of the highest floods, the depth and rapidity of the river, and the kind and dimensions of the timber that can be procured.

In rivers which are tranquil, of little depth, and not subject to high and rapid floods, the number of piers may be augmented without inconvenience, provided they do not interrupt the navigation of the river nor contract too much the water-way.

But if the bridge have to cross a torrent, the least possible number of supports should be

* Respecting the velocity of rivers, and the fall of water under bridges, the reader may consult Dubuat's *Principes d'Hydraulique;* Dr. Robison's article "River," *Encyclopædia Britannica;* Playfair's *Outlines of Natural Philosophy; Rees's Cyclopædia,* Art. "River," by Mr. John Farey; Hutton's *Tracts;* Sir H. Douglas on *Military Bridges; Dr. Brewster's Encyclopædia,* Art. "*Hydrodynamics*"; and *Hydraulic Tracts.*

† *Edinburgh Philosophical Journal,* No. 1.

placed in the stream. When the banks are not too low, and the width of the river does not exceed 300 feet, the engineer should give the preference to one arch. When more than one arch is required, much expense cannot be saved by making the span of the arches large, because the piers in such cases require to be carefully constructed, and there will be much additional labour, and consequently expense, both in the arches and piers. But if the opening be not greater than can be spanned with one arch, it would certainly be the best method to do it so, especially if the banks be high on each side.

280.—The rise of the arch or arches is generally limited by the form of the roadway and the height of the highest water-line, as that line should be the springing of the arch. The roadway should always be of as easy an ascent as circumstances will admit of; ascending from each side to the middle in a rise of about one part in 36, gives the bridge a slight curvature, which improves its appearance; but it ought not to rise at a quicker rate than one part in 12. On this subject Smeaton remarks, that the ascent of Westminster Bridge was originally laid out to be one part in 20, but he apprehends it to be at least one in 12; he further observes that, in laying out roads and bridges, if the ascents do not exceed 3 inches per yard, they are in no way objectionable.* Alberti states the ancient rule to be one in 30, with sometimes a quicker rise at the centre of the arch, but so short that an animal might draw a load over it at one effort. Ludgate Hill rises only one in 36, and when it is possible to construct a bridge with so gentle a rise it is much more desirable. Telford mentions one in 24 as a convenient ascent for a bridge;† and it is perhaps that which will in general be found best to agree with the other circumstances to be attended to in the erection of a bridge.

Wiebeking also names a rise of one in 24 as that which may be used without inconvenience; but he observes that in timber bridges the settlement is generally about one part in 72; that is, if a timber bridge of 144 feet span rise one foot in the middle when first framed, it will settle so as to become nearly horizontal; therefore, when it is intended that the bridge shall have an ascent of one in 24 when finished, it must be framed so as to have a rise of one in 18; for

$$\frac{1}{1} = \frac{1}{24} + \frac{1}{72}.$$

281.—But when the rise of an arch or truss is limited, whether it be by the form of the roadway or any other local circumstance, the span is also limited; for if the span does not bear a certain proportion to the rise, the bridge will not support its own weight. This proportion depends on the radius of curvature of the curve of equilibrium, and from the length of this radius we may also determine to what extent a single arch may be constructed. The largest span of which we have any correct account being executed with timber is the bridge over the Limmat, near Wettingen; this span is 390 feet, the whole rise about 43 feet, and the radius of curvature of the curve of equilibrium about 600 feet.

It has been found by experiment that the force required to crush a square inch of oak is 5,147 lbs., and suppose one-fifth of this force to be a sufficient load to trust upon each square inch in a bridge, this force would be equivalent to the weight of a column of the same

* Smeaton's *Reports*.

† *Edinburgh Encyclopædia*, Art. "Bridge."

material 2,950 feet high. And it is shown by writers on the strength of materials, that in an arch of the same material, of which the radius of curvature is equal to the height of this column, the parts of the arch will be pressed with the same force as the weight of the column. (See Art. 130.)

Consequently, in a bridge constructed of oak, the radius of curvature should never exceed 2,950 feet; and for fir it should not exceed 3,000 feet.

But then the construction is similar to a framed lever; the abutments being secured by a horizontal tie, the radius of curvature of the curve of equilibrium of the compressed part of the frame, when it is sufficiently loaded with its own weight, will be only half the height of the column that would produce an equal pressure on the same base, because in this kind of construction there is at least double the weight of materials. Therefore, in a bridge with horizontal ties, the radius of curvature should not exceed for oak 1,475 feet, for fir 1,500 feet.

These numbers only give the radius when the frames, or ribs, are sufficiently loaded with their own weight; but there is the roadway and the timbers connected with it, which add nothing to the strength of the bridge. But the radius of curvature of a bridge which will be sufficiently loaded when the whole weight to be laid upon it is taken into consideration, may be found by the following proportion:—

As the whole weight of the bridge
Is to the weight of the supporting frame;
So is the radius of curvature above determined
To the radius required.

The following table shows the radius of curvature when the weight of the supporting frame is to the weight of the whole in the ratios stated at the head of the columns:—

Kind of construction.	Radius of curvature.			
	Weight of roadway, &c. 5 Weight of frame .. 1	Roadway, &c. 6 Frame .. 1	Roadway, &c. 8 Frame .. 1	Roadway, &c. 10 Frame .. 1
	feet.	feet.	feet.	feet.
Curved ribs of oak supported by abutments	520	422	330	270
Ditto, of fir, ditto	600	430	334	273
Framed with horizontal tie, oak	492	370	295	246
Ditto, fir	500	375	300	250

These calculations suppose the parts of the bridge to be accurately balanced, according to the principles of equilibrium; and it is obvious that any defect in this respect must render it necessary to increase the curvature.

Wiebeking, in his work on Bridges, gives some proportions for the rises for different spans, but not from principles; his proportions being founded entirely upon the observations he had made in practice. As far as regards appearance, he states one-tenth of the span to be the best proportion for the rise of an arch; but as it is in general desirable to keep bridges low, he gives the following proportions:—

From	100	to	150	feet span	make the rise	$\frac{1}{20}$
"	"		200	"	" "	$\frac{1}{18}$
"	"		300	"	" "	$\frac{1}{15}$
"	"		400	"	" "	$\frac{1}{14}$
"	"		500	"	" "	$\frac{1}{13}$
"	"		600	"	" "	$\frac{1}{12}$

Wiebeking says, that experience had convinced him that larger spans require a greater rise than small ones; but it will be seen from the table given in Art. 296, that large spans require even a greater rise than he has assigned to them; indeed, his proportions are not to be depended upon beyond 300 feet spans; nearly so far he has had experience; and to determine the least rise for larger spans, the rules above laid down, or others derived from the same principles, are the only ones to be depended upon.

It is of considerable importance to know the radius of curvature that should not be exceeded for different materials, as it determines at once the least rise which ought to be given to an arch when the span is known, as well as the extent of span when the rise is known. Perhaps some may imagine that we have undervalued the strength of the materials in taking only one-fifth of the force that actually produced fracture; but it must be remembered that when fracture takes place, the piece submitted to experiment is generally shortened about one-third of its length; now, as the quantity of compression is as the force, nearly, one-fifth of the force would reduce the length almost one-fifteenth part, which would produce a degree of derangement in a system of framing that should never be found in a bridge.

CONSTRUCTION OF THE ABUTMENTS AND PIERS.

282.—The abutments and also the piers should be executed in stone, in which case all that relates to the construction of them falls within the mason's department: nevertheless, as they should be capable of sustaining the thrust of the arch where there is not a horizontal tie, we give the following rule for finding the proper thickness; the abutments being rectangular, and the weight of a cubic foot of the stone-work 120 lbs.

RULE. Multiply the square of the height of the abutment by 160, and divide this product by the weight of a square foot of the arch, and by the rise of the arch; add unity to the quotient, and extract the square root.

Diminish the square foot by unity, and multiply the root, so diminished, by half the span of the arch, and by the weight of a square foot of the arch.

Divide the last product by 120 times the height of the abutment, and the quotient will be the thickness of the abutment.

Example. Let the height of the abutment from the base to the springing of the arch be 20 feet, half the span 100 feet, the weight of a square foot of the arch, including the greatest probable load upon it, 300 lbs., and the rise of the arch, 18 feet. Then $\frac{160 \times 20 \times 20}{300 \times 18} = 11{\cdot}852$, and $11{\cdot}852 + 1 = 12{\cdot}852$. The square root of 12·852 is 3·6 nearly; and $3{\cdot}6 - 1 = 2{\cdot}6$. Also $\frac{2{\cdot}6 \times 100 \times 300}{120 \times 20} = 32{\cdot}5$ feet, the thickness required.

The abutment thus determined is one-fourth above that which would barely resist the thrust of the arch, besides the additional stability it receives from that part of the height above the springing. In order to prevent any risk of sliding at any of the joints of the masonry, it would be an advantage to incline them towards the opening of the arch, making the inclination less and less as it approaches the base. In *figs.* 1 and 3, *Plate* XXXIX., the joints are drawn in the manner proposed.

283.—The thrust of a timber arch and the strength of pier required to support it may also be determined by the same method as that employed for segmental arches of stone or brick (see *The Science of Building*). Let N represent the horizontal thrust at the crown of 1 foot width of the arch; P the weight of 1 foot width of the half-arch and its load; z the rise of the arch, s its span; h the height of the pier, and t its thickness. Then in equilibrium we have—

$$N \cdot z = P \frac{s}{4}, \text{ or } N = P \frac{s}{4z},$$

Let Q be the weight of 1 foot width of the pier, then the equation for equilibrium is

$$N \cdot h = P \cdot t + Q \frac{t}{2}.$$

Taking the load at 300 lbs. per foot square, and the weight of the pier at 120 lbs. per cubic foot, this equation becomes

$$5 \frac{h}{z} s^2 = 20 s \cdot t + 8 h \cdot t^2.$$

Applying this to the above example, we have, $h = 20$, $s = 200$, $z = 18$; therefore, N = thrust upon top of the pier $= 300 \frac{200^2}{8 \times 18} = 83{,}333$ lbs. for every foot width of abutment. And the equation for equilibrium becomes

$$1389 = 25 t + t^2.$$

Therefore $t = 26{\cdot}8$ feet, the thickness which is just enough to balance the thrust of the bridge. Adding one-fourth for stability gives 33·5 feet for the thickness of the pier, which is 1 foot more than was obtained by the foregoing rule, and is one-sixth of the span.

PIERS.

284.—When piers are necessary, either to save expense, or to reduce the span of the arches to a practicable extent, to construct them of stone is the best method, as piers of timber very rapidly decay: the timber in a wooden pier being exposed to the alternate action of dryness and moisture, and consequently in the worst situation timber can be placed in.

Stone piers for wooden bridges have been used in many situations: the following table shows the span of the arches and thickness of the piers in some of the principal ones:—

Name of Bridge, &c.	Span of centre arch.		Thickness of piers.		Thickness of pier in parts of span.
	feet.	inches.	feet.	inches.	
Bridge over the Schuylkill, at Philadelphia (Art. 267)	194	10	27	7	$\frac{1}{7}$
Bridge at Trenton, over the Delaware (Art. 265) ...	200	0	19	0	$\frac{2}{21}$
Bridge of Tournus, over the Saone, France*	89	6	16	6	$\frac{2}{11}$
Bridge of Choisy, over the Seine, France*	67	6	9	10	$\frac{1}{7}$

It will be seen that considerable latitude has been taken in fixing the dimensions of stone piers. If it be considered that they should be capable of withstanding the thrust of the arches, their thickness should be found by the same rule as has been given for the abutments; the ends of stone piers should be of a parabolic form in order that the water may glide easily between them.†

285.—When timber is used for piers, they may, in simple cases, be constructed by driving a single row of piles for each pier in a line with the current of the river. The piles may be from 10 to 14 inches square, and placed at from 2 to 4 feet distance from one another. The piles should be strengthened by oblique braces. *Fig.* 8, *Plate* XXXVI., represents a pier of this kind.

In a deep river, or where the height of the roadway is much above the surface of the water, it is difficult to get piles of sufficient length. In such a case the piles may be driven and cut off a little below low-water mark, and upon these piles posts may be placed for supporting the roadway. The joinings should be secured by means of horizontal pieces well bolted together. A, B, and C, *fig.* 1, *Plate* XLV, show the way in which the upper and lower parts of the pier should be connected.

The piers of the Bridge of St. Clair, at Lyons, are constructed nearly in this manner,* and it has the advantage of giving good hold to the piles, besides rendering them much easier to drive; it also cuts off the connection between the part of the pier which is constantly wet, and of long duration, and that which is alternately wet and dry; consequently it is much easier to repair or renew the posts, which will from their situation often require it.

* Gauthey, *Construction des Ponts.*

† See Dubuat's *Principes d'Hydraulique.*

But when the depth of the river is very considerable, it would not be safe to trust to a single row of piles; in that case the lower part should consist of a double row of piles, B, B (*fig.* 2, *Plate* XLV.), at about 3 feet distance from middle to middle, connected by the horizontal beams EE, and the cross pieces DD, for supporting the posts.

In order to secure the feet of the posts, they must be clasped by two horizontal ties, CC, and the whole well bolted together.

Fig. 8, *Plate* XXXVI., and *fig.* 6, *Plate* XXXVII., show how the posts may be braced; and when their height is considerable, one or more courses of horizontal ties will be required besides the inclined braces.

286.—Instead of driving piles for the piers or supports of a wooden bridge, Telford adopted another method with perfect success on the river Severn, about eight miles below Shrewsbury. He made choice of any convenient situation on the banks of the river for constructing the pier, which consisted of an upright frame having a grated frame attached so as to form its base, the base extending on each side of the upright frame. The framing was then sunk in its proper situation, the bottom having been carefully levelled to receive it.

Through the spaces in the grated frame short piles were driven to keep the whole secure in its place. The sides of the upright frame were covered with planking, and in order to add to the stability the lower parts were filled with gravel and small stones.

To prevent ice, or other bodies carried down by the current, from injuring the piers, the edges of the frames which face the stream had triangular pieces of cast-iron fixed upon them.* Fender piles were also sometimes driven so as to form a triangle at a little distance above and opposite to each pier.

287.—When a river is subject to ice floods, the piers should be protected by ice-breakers, which should be detached, in order that the bridge may not be injured by the shock of bodies descending with the current. The ice-breaker, A, B, *fig.* 5, *Plate* XXXVII., consists of a single row of piles, connected by two horizontal beams, with an inclined capping, the edge of which is protected by a triangular prism of cast-iron.

Fig. 3, *Plate* XLVI., is a plan and side elevation of an ice-breaker, consisting of two rows of inclined piles; the heads of which abut against an inclined capping, protected with iron as before. The inclined sides to be covered with planking, which is not shown on the engraving.

In a large bridge there is little danger to be apprehended from connecting the ice-breaker with the pier.

The Bridge of Freysingen, already described, Art. 269, is an example of a timber pier of a different construction, which is well worthy of the reader's attention.

But after every precaution is taken to ensure the durability of wooden piers, they almost always are in a state of decay before the superior parts of the bridge; therefore they should only be used where it is difficult to procure stone: in such cases the modes of construction adopted by Telford and Wiebeking may be employed with advantage.

* *Edinburgh Encyclopædia*, Art. "Bridge."

CONSTRUCTION OF THE ARCHES AND TIMBER FRAMES FOR WOODEN BRIDGES.

288.—Before proceeding to specify the modes of construction adapted to particular cases, a few observations on the general principles of construction will perhaps render the advantages of the methods proposed more evident, and, what is of more importance, will improve the student's notions of the subject.

Let AB, *fig.* 1, *Plate* XXXVIII., be a solid beam resting upon the supports A and B. If we suppose this beam to be the support of a roadway, it will, besides its own weight, have to support the planking and road, as well as that of any heavy body moving over it.

A beam may be made stronger, with the same quantity of timber, by making it deeper in the middle, and less at the ends, as in *fig.* 2; for a strain at C will have less effect in bending that beam, than one at the middle of the length, and the strength will be nearly as the square of the depth at the middle. And, however the weight may be distributed, if it be sufficiently great it will cause the beam to bend; and when a beam bends, it is observed that the fibres at the upper side d are compressed, and that those on the lower side e are extended. Also that there may be a line drawn at the middle of the depth $a\ c\ b$, where the fibres are neither extended nor compressed, but remain in their natural state. But all the fibres between c and d are compressed, and all those between c and e are stretched; though not equally so, because the nearer a fibre is to the points d or e the more it is strained. (See Art. 81.)

Now as the middle part of the depth of the beam is very little strained, in comparison with the upper and lower sides, it is clear that we can employ the same quantity of timber in a more effectual manner by using a deeper beam, cutting it down the middle, and framing the parts together as is shown in *fig.* 3. Because we have seen that the middle part exerts very little force, and its weight is a considerable load on the beam.

If D is the depth $d\ e$ in *fig.* 3, and d the depth of the space between the upper and lower parts, then $D - d$ is $d\ e$ in *fig.* 2. The strength of the beams may be taken as nearly proportional to the squares of the depths at the middle, or as $D^2 - d^2$ to $(D - d)^2$, or as $D + d$ to $D - d$. If $D = n\ (D - d)$, then $d = (n - 1)\ (D - d)$, and $D + d = (2\,n - 1)\ (D - d)$, or the strength of *fig.* 3, is to that of *fig.* 2, nearly as $2\,n - 1$ to 1. If $n = 3$, then the strength of the former is five times that of the latter.

If we now attend to the forces exerted by the parts of the beam, it will be found that the upper part, $a\ m\ d\ n\ b$, is wholly compressed in the direction of its length, and that the lower part, $a\ r\ e\ s\ b$, is wholly extended in the direction of its length; and it is well known that timber offers the greatest degree of resistance when strained in the direction of its length, provided the necessary degree of security can be given to the joints.

289.—From these considerations we are naturally led to the kind of construction shown by *fig.* 4, where it is obvious that the same pressures obtain as in the perforated beam above described; the only difference being, that here the tie-beam is supported, as otherwise it would fail in large spans. The celebrated bridges of Schaffhausen, Zurich, Landsberg, and Wettingen are constructed on this principle. In the bridge of Schaffhausen the disposition of the timbers is nearly the same as is shown by *fig.* 4. The continued tie AB retaining

and being an abutment for the compressed beams, the frame requires only to be supported, and has no other thrust on the abutments of the bridge than a solid beam would have. Framed bridges, such as that designed by Palladio, *fig.* 1, *Plate* XXXVI., may be referred to the same principle.

It is easy to conceive that the tie might be entirely removed, provided the abutments were made capable of sustaining the thrust. This, without any other change, leads us to the kind of construction represented in *fig.* 5, which has been adopted by Joseph Ritter for a bridge across the torrent of Kandel, in the canton of Berne.* Mr. Semple has given a design for a bridge on this principle.†

But as long pieces of timber require to be of a proportionate depth and breadth, consequently are not easily procured, and in scarfing much of their strength is lost, a kind of construction where short timbers only can be procured is desirable. *Fig.* 6 represents a combination which may be used in such cases with advantage. Such a combination has been often employed; we have an example in that of Palladio across the Brenta (see *Plate* XXXVI., *fig.* 3); and the Bridge of St. Clair, over the Rhone at Lyons, is of the same kind.

We cannot, however, derive much benefit from shortening the beams, by dividing the span into shorter lengths, because the angles of junction become more obtuse or open, and of course the strain in the direction of the pieces is much increased. And, however strong such a bridge might be, in respect to a constant load distributed over it, the weight of any load moving upon it would soon derange it; because the strength of such a system to resist a variable load must depend wholly on the strength of the joinings, to which it is difficult to give much strength. Nevertheless, bridges have been both designed and executed on such principles, as is represented by *figs.* 7 and 8. The combination, *fig.* 7, resembles the Bridge of Mulatiere, at Lyons, over the Saone;‡ and *fig.* 8 is combined nearly in the same manner as the arches of the bridge at Walton, which was found in a state of decay in twenty years.§ The Bridge of Sault, on the Rhone, was also on the same principle as *fig.* 8, and failed within thirteen years.‖

290.—From combinations of the kind last noticed, the continued curved rib, in the manner proposed by Price (see Art. 259) naturally succeeds, which possesses advantages not to be found in a series of beams merely abutting end to end. For when the rib is built of short lengths with the joints crossed, and the different thicknesses firmly bolted together, it becomes as one solid beam. If we suppose the straining force to be applied at D, *fig.* 9, then the force must be sufficient to fracture the rib at C, D, and E; therefore, when the strength of the rib is capable of sustaining the strains of C, D, and E (see Section II., Art. 130), and the curve is a proper curve of equilibrium to the constant load (see Section I., Art. 59), this is at once a simple and effectual combination. The use of curved ribs of this kind, it has been already noticed, appears to have been known at a very early period (Art. 256); but it has been only

* This bridge is described by Gauthey, *Construction des Ponts*, and also by Rondelet, *L'Art de Bâtir.*

† Semple on *Building in Water.*

‡ Gauthey, *Construction des Ponts.*

§ Smeaton's *Reports.* An engraving of Walton Bridge, from a drawing by Mr. John Farey, is given in *Rees's Cyclopædia.*

‖ Gauthey, *Construction des Ponts.*

lately that they have been extensively employed in the construction of bridges, and it has been further improved by bending the pieces which form the ribs. Among other considerable structures on this principle may be noticed, in France, the Bridge of Choisy on the Seine, and that of Chazey on the Ain (the former 67 feet, and the latter 64 feet span): the Bridge of Tournus on the Saone, built in 1801, of nearly 90 feet span; in Bavaria, a bridge near Oettingen, on the river Inn, built in 1807, of 103 feet span; the bridge near Freysingen, on the Isar, of 153 feet span, built in 1808; and the bridge near Bamberg, over the Regnitz, of 208 feet span, built in 1809. The last three were designed by Wiebeking,* and two of them are represented in *Plate* XXXVII. A rib composed of bent beams is shown by *fig.* 10, *Plate* XXXVIII.

It may not be altogether useless to remark, that cast-iron bridges have been constructed nearly on the same principle as *fig.* 9; the finest specimen to be seen is the Southwark Bridge, consisting of three arches, the span of the centre arch being 236 feet. It was designed by Mr. Rennie.†

291.—As a bridge with a curved rib, when the span is considerable, yields at D, C, and E (*fig.* 10) when the load is applied at the middle, the strength must of course be increased by increasing the depth of the rib; and consequently a framed rib, such as is shown by *fig.* 11, is the next step in the progress of improvement. Here, however, it must be observed, that the two curved ribs must be continuous, and put together so as to resist either extension or compression, as in *fig.* 10. For when a load is placed at D, the lower rib will be extended at *d*, and compressed at C and E; while the upper one will be compressed at D, and extended at *c* and *e*. And a weight applied at any other point would produce a similar effect. When the span becomes so great that two curved ribs can be introduced without being made smaller than is required for the firm connection of the parts of each rib, then framed ribs would be a vast addition to the stability of the bridge. Many designs bear a near resemblance to this kind of construction—such, for example, as that by Palladio (*Plate* XXXVI., *fig.* 2); but it is clear that such designs possess no other advantage than framed voussoirs, and they are well adapted for iron bridges where firm connection cannot have place without endangering the structure, in consequence of the expansion of the material.

In timber, however, where we have nothing to fear from expansion, it is losing one of the greatest advantages of the material to interrupt the connection of the parts; besides, numerous joints should always be avoided, both on account of the difficulty of making them fit, so as to bring every part alike into action, and the difficulty of preventing decay at such joinings.

In some instances it is difficult to form abutments, and also desirable to keep the roadway as low as possible; in such cases, *fig.* 12 shows a kind of construction that may be used. It is peculiarly adapted to a situation where the banks of the river are low, and where there is no navigation to interrupt. Where the width of the bridge is considerable, a rib may rise in the middle of the width, so as to divide the roadway into two parts. Sometimes a double rib might be placed in the middle, with a footway between. But where there is much attention paid to architectural effect, bridges with framing to rise above the roadway will seldom be adopted.

* Gauthey, *Construction des Ponts.*

† The Southwark Bridge is described in the Supplement to the *Encyclopædia Britannica*, Art. "Bridge."

As cross-ties will be necessary at the top, the middle parts might be covered with a roof to protect them; also a continued coping, *a a á á*, might be put over each truss, which would improve the appearance, as well as protect the framing.

An example of a small bridge of this character is given in *Plate* XL., the span being 26 feet and the width of the roadway 13 feet. Each rib is composed of four planks, 12″ × 3″.

In the construction of bridges of this description, great care should be taken to prevent the wet from getting between the several thicknesses of timber; a coat of white or red lead is sometimes used, but brown paper, with a free use of Stockholm tar and an admixture of pitch, applied hot, is found to preserve the timber effectually from rot.

292.—We have now noticed each of the simple combinations, and, having shown the general principles of forming such combinations, the carpenter will find it easy to span any opening within the limits pointed out in Art. 281 of this Section.

When the distance of the abutments, or piers, does not exceed 16 feet, a bridge may be constructed by simply laying beams across the opening of about 15 inches deep, by 8 inches in breadth, and about 2 feet apart. For foot-bridges this kind of construction may be extended to 18 feet, with the same scantlings. When the extent of bearing for a bridge for carriages does not exceed 35 feet, the kind of bridge shown by *fig.* 3, *Plate* XXXVI., may be adopted. When there are more openings than one, any of these simple forms might be much strengthened by continuing the beams over more than one opening, when the timber is long enough; and when it is not, by scarfing the beams together at the points of support. Also, short pieces of timber may be placed under each beam, extending from 5 to 7 feet on each side of the cap of the pier, as at AA, *fig.* 3. The Bridge of Bassano is here given as an example of this kind of construction. It was constructed at a place where the river was 180 Vicentine feet wide (194 English feet), which was divided into five equal spaces by the piers. Each pier consisted of eight piles 30 feet in length, and 18 inches square, placed 2 feet apart. The width of the bridge was 26 feet. (See Palladio.)

The strength is sometimes further increased by trussing the railing on each side of the roadway. A temporary foot-bridge, designed and executed by Mr. P. Nicholson in 1808, over the Clyde at Glasgow, is a very good model, and is peculiarly well adapted for any situation where lightness of appearance is desirable. It consists of nine spans, 42 feet each; the roadway longitudinally is the curve of a parabola. (See Nicholson's *Architectural Dictionary*.)

293.—As it has been shown that curved ribs are preferable to other methods of spanning a wide opening, it will only be necessary to select two or three cases as examples. If the span is not more than 50 feet, each rib may be composed of two or three thicknesses of planks of a convenient length, bolted together, and the joints crossed; one of three thicknesses is preferable. The ribs should rise as much as an attention to the form of the roadway and other circumstances will allow: and they should be about from 6 to 9 feet apart, with the roadway supported by upright pieces in pairs, notched and bolted to the ribs. As the weight of the roadway presses in a vertical direction, and it may be considered as a general principle, that each piece (when possible) should be placed in the same direction as the force that it is intended to sustain acts in, therefore the reason for placing them upright is evident. The distance of the upright pieces should never exceed

15 feet, and horizontal cross-ties should be placed at the same points, with diagonal braces, to prevent the bridge from vibrating sideways when heavy loads are moving over it. Diagonal pieces should also be inserted between the road timbers, as lateral motion should as far possible be prevented.

294.—In larger spans, that is, in spans exceeding 50 feet, there will be difficulty in obtaining timber deep enough for the ribs; therefore they should be built the contrary way, and bent to the required curve, so as to increase the depth. The beams forming the ribs should be scarfed at the joinings; the form of the scarf should be such as would resist either pressure or tension (see Section IX., Art. 311), and the scarfs should be kept as distant from one another as possible. The number of thicknesses in each rib must depend on the size required for the span, and the dimensions of the timber that can be procured; and the whole should be well bolted together. The supports of the roadway and diagonal braces to be placed as described in the last Article.

Fig. 1, *Plate* XXXIX., represents a bridge designed for a 200 feet span; *fig.* 2 is a section across at CD to a larger scale. This bridge is sustained by four ribs, each rib 18 inches thick, and 4 feet deep; the ribs to be two thicknesses in width, and either three or four in depth, according to the size of the timber; the lengths of timber should be disposed so as to cross the joints as much as possible, and the joints should be scarfed. One of the most simple scarfs will be the best adapted for that purpose. The pieces composing a rib must be well bolted together, and keys in the joints would be a further means of preventing any sliding of the parts.

The vertical pieces which support the roadway are intended to be put on in pairs, notched to the ribs, and bolted together, and not more than 18 feet apart. And at each pair a double tie is intended to cross both the back and the under side of the ribs, notched on to the ribs, and bolted to the vertical pieces.

Between the timbers which carry the joists of the roadway diagonal braces should be framed so as to secure the bridge from lateral motion. A series of braces for the same purpose might be framed over the back of the ribs; but one of these methods, if well executed, will be sufficient.

The bridge is intended for a gravel or paved roadway, and is calculated to sustain two loaded waggons at its weakest point without injury.

This kind of bridge is adapted to any span that is usual in bridge building; the ribs should not be more than 8 feet apart, and their dimensions may be easily calculated for any span by the help of Art. 298 of this Section, and Art. 130 of Section II.

As the beams are intended to be bent to the form of the rib, it will be prudent to ascertain whether such a degree of curvature may be given to the beams without impairing their elastic force. The curvature to be given to the beams will be sensibly uniform, and the degree of uniform curvature which may be given to a beam is inversely as its depth, or the radius of curvature will be directly as the depth. But it has been shown by Dr. Young that the deflexion of a beam uniformly curved is to that of one bent, by a load placed in the middle of its length, as 3 is to 2; and as Mr. Barlow has determined the degree a beam will bend without destroying its elasticity by experiment, on these data a rule for the depth of the beams for a curved rib may be established.

Let x be the deflexion found by experiment upon a beam, of which half the length is y;

then $\frac{3x}{2}$ will be the deflexion corresponding to an uniform curvature; and $\frac{y^2}{3x}$ = the radius of curvature; the deflexion being small when compared with the length.

If the depth of the beam employed for the experiment be d, and R the radius of curvature of the bridge, we have $\frac{y^2}{3x} : R :: d : \frac{3xdR}{y^2}$ = the depth of the beams which may be employed for the curved ribs.

Hence, from Mr. Barlow's experiments, we have—

For English oak	...	·05 R	= the depth of the beam in inches.
For Riga fir...	...	·035 R	= the depth of the beam in inches.
For larch ...	...	·077 R	= the depth of the beam in inches.

Wiebeking has made some experiments on bending beams on a very large scale, which tend to prove the correctness of the method above used in finding the depth. He observed, that when several pieces were placed one upon another they would curve much more without fracture than a single piece would do.

The radius of curvature of the Bridge of Bamberg was 422 feet, and 422 × ·035 = 14·77 inches. The depths of the beams employed were from 13·5 to 15·5 (see Table, Art. 271); the depth given by our rule is nearly a mean between those that were used.

295.—If the span be greater than 250 feet, instead of single curved ribs it would be an advantage to make frames each consisting of two curved ribs, with radial pieces, and crosses between, as shown in *fig.* 3, *Plate* XXXIX. The ribs should be formed as described in the last article. The radial pieces should be notched on to the ribs, in pairs, and bolted together; the diagonal pieces, or crosses, halved together in the middle, and made to abut end to end between the radial pieces. See *figs.* 4 and 5. *Fig.* 4 shows a plan of the framing, and *fig.* 5 a section across at the middle.

At AB, *fig.* 3, horizontal ties are notched and bolted to the vertical supports, so as to brace them in both directions; and a series of diagonal braces might be applied upon the horizontal cross-ties, which would be very effectual in stiffening the bridge against lateral motion. The braces shown by dotted lines in *fig.* 5 need be applied only at four or five places in the whole length of the bridge. The roadway to be formed and supported as in the preceding examples.

296.—The rise of the curve should never be less than that determined by the equation $\frac{s^2}{2\sqrt{(h^2-s^2)}} = r$ = the rise of the curve, of which s is half the span and h is the height of a column of matter which would produce the same pressure upon its base as the greatest pressure that ought to be transmitted through the framing. For let a be the area of the frame, and g the weight which this area might bear with safety; also let n be the weight of a foot in length resting on the frame, of which the area is a, therefore sn = the weight of the semi-arch. In a wooden bridge the load is so nearly uniform, that the curve of equilibrium may always be considered a parabola, therefore we have $2r : \sqrt{4r^2+s^2} :: sn : \frac{sn\sqrt{4r^2+s^2}}{2r}$ = the pressure at the abutment in the direction of the frame; which should be $= g$ Whence we obtain, $r = \frac{s^2}{2\sqrt{\left(\frac{g^2}{n^2}-s^2\right)}}$, and $\frac{g}{n} = h$, $r = \frac{s^2}{(\sqrt{h^2-s^2})}$. This is the equation used in calculating the table.

In large arches the ratio of the weight of the supporting frame will be to that of the part supported in general nearly as 1 to 6, and in small spans as 1 to 10; whence the reduced value of h will be, for timber, about from 430 feet to 270 feet. The following table shows the least rise corresponding to each span, which will be more convenient for use than the one given in Art. 281 :—

Table of the least rise for different spans.

Span in feet.	Least rise in feet.	Span in feet.	Least rise in feet.	Span in feet.	Least rise in feet.
30	0·5	120	7	280	24
40	0·8	140	8	300	28
50	1·4	160	10	320	32
60	2·0	180	11	350	39
70	2·5	200	12	380	47
80	3·0	220	14	400	53
90	4·0	240	17	...	...
100	5·0	260	20	...	...

It must be remembered, that a small rise should be avoided, if possible, because it requires a much greater quantity of timber to make the bridge equally strong.

The proper curve of equilibrium may be found by the principles laid down in Section I., Art. 62 to Art. 65. But in general it will differ very little from the common parabola, which is easily described. (See Section IV., Art. 182.)

Wooden bridges, however well they may be executed, will always settle a little immediately after construction, and this will increase in a small degree with time. Wiebeking has made some observations on this subject, and has found that the settlement in the middle may be expressed in inches by $\cdot 806 \frac{r}{s}$, where r is the rise in feet, and s the whole of the span in feet.

OF THE ROADWAY.

297.—The roadways of bridges are constructed in various ways; but the most usual one is to pave upon gravel; sometimes gravel only is used, and some prefer planking only.

The planking in small bridges is often laid immediately upon the principal beams, which in such cases are placed about 2 feet apart, as in *fig.* 6, *Plate* XXXVII.; but it is better in respect of durability to lay cross joisting for supporting the planking; these joists should be about 2 feet apart, and the planking laid upon them, which may be from 3 to 4 inches thick. The cross joints admit the air to circulate more freely round the principal timbers, and therefore render them more durable. *Figs.* 2 and 5, *Plate* XXXIX., show the latter of these modes of construction.

Where bridges are intended for wheel carriages, there thould be a separate footpath, which may be paved with flag-stones. Footpaths are made from 2 feet to 6 feet wide, according to the number of passengers. The carriage-way may be paved upon a bed of gravel of about 12 inches in depth; the paving to rise in a curve across the road. The gravel should contain a considerable portion of tempered clay, so as to bind it firmly together; but if there be too much clay, it will shrink and crack in drying. Belidor states, that paved bridges are the most durable.*

If the roadway should be covered only with gravel or broken stone, it should be from 12 to 18 inches deep in the middle, and from 9 to 14 inches deep at the sides, according to the traffic over the bridge. Whether the roadway be paved or gravelled, means of conveying off the water should be provided.

As the moisture which passes the gravel or broken stone soon rots the planking, it is supposed to be better to lay an additional thickness of planking, and no gravel or paving. In that case the upper planking should lay across the bridge to prevent the feet of horses sliding. It would be easy to renew such a roadway; but we do not see any other advantage it possesses.

Parapets or bulustrades are made from 3·5 feet to 6 feet in height above the footpath; 4 feet is enough for protection. The railing is stayed by braces on the outside. Iron railing is sometimes used.

The railing should, however, partake of the character of the surrounding scenery. In towns, upright or diagonal bars and other ornamental railing may be used; but in all cases where trees and cottages form the most striking features of the surrounding landscape, simple horizontal rails with posts are preferable. Nothing is more formal and stiff than ornamental or upright railing, and nothing more picturesque than the simple continuous lines of horizontal rails.

Wooden bridges have been often covered with a roof. The bridges of Schaffhausen, Wettingen, Kandel, Mellingen, and several American bridges, were roofed; but as the roof does not appear to be of much service in protecting the bridge, it has been latterly generally omitted. The planking of the roadway might be protected very much by a coat of pitch, tar, and sand, or asphalte. (See Section X., Art. 375.) A composition of this kind was used for covering the planking under the roadway of the iron bridge over the Wear at Sunderland.

ON DETERMINING THE SCANTLINGS OF THE TIMBERS FOR BRIDGES.

298.—The greatest load likely to rest upon a bridge at one time would be that produced by its being covered with people. It should be such that the crowded procession may move along in perfect safety; and it is easily proved that this is about the greatest load a bridge can possibly have to sustain, as well as that which creates the most appalling horror in the case of failure. Such a load is about 120 lbs. per foot, and, together with the weight of the framing and gravelled roadway, would be about 300 lbs. on a superficial foot, or 0·14 of a ton. And as this load may be supposed to be uniformly diffused over the bridge, half

* *Science des Ingénieurs.*

the load upon it will be expressed in tons by $0{\cdot}14\,w \times s$, where s = half the span, and w is equal the width of the bridge.

If the bridge be only planked without gravel, as a foot-bridge, the greatest probable load will be expressed in tons by $0{\cdot}09\,w \times s$.

Now, as the load is sensibly uniform, the curve of equilibrium will be a common parabola; and when the rib is of this form any uniform load would have no tendency to produce any derangement or other strain in the rib than that which is propagated in the direction of the curve. Therefore the first object must be to determine the size of the ribs, so that they may be capable of resisting this pressure without being more compressed than is consistent with the stability of the structure.

Riga timber suffers a compression in the direction of its length of about one fifteen hundredth part of its length under a load of 64 tons upon a square foot; and oak bears about the same load with the same degree of compression. Under such a pressure the curved rib of a bridge 200 feet in length would shorten rather more than 1·6 inches; and as it is a material that soon decays, this will not appear too low an estimate of its strength.

The pressure in a bridge increases towards the abutment; but it is advisable to increase the depth of the rib at the abutment; therefore we may estimate the pressure at the crown, which simplifies the operation.

The pressure in the direction of the rib at the crown is the same as the horizontal thrust, and may be determined by Art. 40, Section I.; but it is more convenient for the present purpose to express it in a different manner.

If x be the rise, and s the half span; then by the resolution of forces, $2x : s :: \text{weight} : \text{pressure}$ in the direction of the curve at the vertex or crown.

Therefore $\frac{0{\cdot}14\,w \times s^2}{2x}$ = the pressure in bridges with gravelled roadways. (A.)

And $\frac{0{\cdot}09\,w \times s^2}{2x}$ = the pressure in bridges without gravel or paving. (B.)

If b = the breadth of each rib, and d = the depth of each rib, also n = the number of ribs: then $64\,n \times b \times d$ = pressure, when the ribs are sufficiently strong.

Hence from equation (A) we have $\frac{0{\cdot}14\,w \times s^2}{2 \times 64 \times x \times n} = b \times d$. (C.)

And from equation (B) we have $\frac{0{\cdot}09\,w \times s^2}{2 \times 64 \times x \times n} = b \times d$. (D.)

From these equations we derive the following practical rules:—

RULE for bridges that are gravelled. Multiply the width of the bridge by the square of half the span, both in feet; and divide this product by the rise in feet multiplied by the number of ribs; the quotient multiplied by the decimal 0·0011, will give the area of each rib in feet.

RULE for bridges where the roadway is only planked. This rule is the same, except multiplying by the decimal 0·0007 instead of 0·0011.

Example. Let it be required to determine the area of the ribs for a bridge of 200 feet span, to rise 15 feet, and be 30 feet wide, with 3 curved ribs. Then the half of the span is 100, and its square is 10,000; and $\frac{30 \times 10000}{3 \times 15} \times 0{\cdot}0011 = \frac{300000}{45} \times 0{\cdot}0011 = 7{\cdot}33$ feet nearly, for the area of each rib. Such a rib may be formed by making it three pieces in depth and

two in thickness, similar to those of the bridge near Bamberg, *Plate* XXXVII., *fig.* 3, or to the design, *fig.* 1, *Plate* XXXIX.

299.—Having now given an easy rule for determining the area of the rib, so that it may resist the greatest pressure that can occur from an uniform load, we must next inquire whether the strength so determined will be sufficient to resist the greatest load that can be applied at one point.

The bridge is supposed to be in a state of equilibrium when acted on by its constant load only; and the greatest strain that can arise from a load collected at one point will take place when that load is applied at one-third of the span from the abutment. But a load so applied must strain the bridge at three points, as has been already stated (Art. 130); and the greatest load likely to be upon one point at a time will never exceed 50,000 lbs., and in narrow bridges it should not be considered more than 20,000 lbs.

Let the load be considered to act at F, *fig.* 9, *Plate* XXXVIII.; then the strained points will be at F, G, and H. If the effect of the connection at F be omitted, the scantling that would sustain any given load at one point may be determined by Art. 130, Section II., where an example is given. The other parts of the bridge, such as the joists and other horizontal timbers, will be easily determined by the rules already given, when the weight to be supported by them is known, and which will of course always be given by the nature of the construction.

In large bridges the depth of rib necessary to secure stability will be always greater than that which would be sufficient to resist the pressure of the uniform load; for, by referring to Art. 130, it will be found that the area of each rib should be 8·83 feet, when there are three ribs for a 200 feet span; but we have seen in Art. 275 that an area of 7·333 feet is sufficient to resist the pressure of the uniform load.

If the amounts of the loads upon a bridge be varied from those above assumed, it will be easy to change them in the rules according to the particular circumstances of the case; it need scarcely be added that the loads should be the greatest probable.

ON THE CONSTRUCTION OF VIADUCTS.

300.—The term VIADUCT is applied to a roadway that is carried horizontally over a wide valley, the sides of which are too steep for the road to pass up and down. Viaducts are chiefly employed for railways where a steep gradient is undesirable; they are generally made with arches of moderate span carried upon a number of piers; unless there happens to be a deep river in the middle of the valley, when the span of the portion over the river is generally made sufficient for the road to cross it without an intermediate pier, as in the case of bridges.

Timber has been much employed in the construction of viaducts both in England and in America in the early days of railways, but either iron, stone, or brick is now used in preference, on account of their greater durability, and most of those originally built of timber have been, either in whole or in part, replaced by more permanent structures.

We shall now give a brief description of some of the railway viaducts which have been constructed of timber in this country.

301.—*Plate* XLII. shows an elevation and section of one opening of the superstructure of College Wood Viaduct, on the Falmouth extension of the Cornwall Railway, erected from the design of the late Mr. Brunel, C.E. The piers are of snecked masonry, the abutments are simply planked platform resting upon the embankment. The struts in the truss are framed, and so arranged that, in case of repair, any one of them can be taken out without injury to the stability of the structure, and can be replaced in a very short space of time, so that the passage of trains need not be interfered with. The iron bracing is distributed so as to prevent one part of the structure lifting when the strain is between the two preceding or two following piers. The timber employed was yellow pine *kyanized*, oak being used for the wedges and butt pieces. This viaduct consisted of fifteen spans 66 feet each, the total length being 964 feet, and the height 105 feet. Each pier consisted of two stone columns 8 feet × 4 feet at the top, with a batter of 1 in 60, and 70 feet high at the centre of the valley.

302.—*Plates* XLIII. and XLIV. show the elevation, sections, and details of piers, &c., of the St. Germans Viaduct, on the Cornwall Railway, erected from the designs of the late Mr. Brunel, C.E. This bridge, which is mainly composed of wood, is constructed on the principle of the truss, the top or compression boom being formed of balks of timber, 12 inches × 14 inches section, three being used at the centre and two at each end of the span. These balks are keyed together, and also united with bolts. The bottom or tension members, composed of flat iron bars, 6 inches × 1 inch section, with rolled heads. On each side of the centre line, and over the piers, vertical pieces of timber are used as struts, and diagonal cross bracing of flat rolled-headed bars is introduced in the space of 28 feet at the centre, between the verticals. These bars are bolted on to the bottom tension bars. In the spaces between the verticals of the truss and those over the piers, are diagonal struts of timber, bolted together, and abutting on the tops of the piers, as shown in *Plate* XLIV. In the centre of the truss a 1-inch bolt is passed through the timbers, and supports the bottom tension bar in a stirrup. The platform is formed of 8-inch timber, placed transversely, with a tie-rod 1½ inches in diameter, over each vertical. A wooden hand-rail, 4 feet 6 inches high, is placed on the top of the truss, as shown in the plate. This viaduct is 942 feet long, and consists of 15 spans, seven of which are 66 feet wide, six are 64 feet, and two are 48 feet. The height of the girders above high-water line of the river is 75 feet. The piers in the waterway consist of groups of wooden piles placed in pairs and driven with a batter of 1 in 15, having cross bracing both vertical and horizontal between the sets. The two piers in the navigable part of the river are furnished with fenders as shown on *Plate* XLIII.; those at the shore end have a masonry foundation 3 feet thick, on which are laid sills of hard wood, 12 inches thick, and on these the piles are placed, the rest of the pier being constructed as those in the waterway.

303.—The Elwell Viaduct, on the Wilts, Somerset and Weymouth Railway, is very similar in design to the above—timber, however, being used instead of iron for the ties. It consists of nine spans 40 feet each, the roadway being supported on queen-trusses, of which the timbers are 12 inches × 12 inches. The piers are formed of timbers 14 inches × 14 inches, 2 feet 4 inches wide at the top, and battering 1 in 20, the base resting on stone foundations. This viaduct is illustrated in *Examples of Bridges and Viaducts*, by W. D. Haskoll.*

* Crosby Lockwood & Co.

304.—A timber viaduct on the South Wales Railway is exactly like the Elwell Viaduct as regards its superstructure, and consists of nine arches of 50 feet span, and two of 30 feet. The height of the truss above the bed of the river in the middle is 50 feet. The piers consist of single rows of piles twelve in number, 16 inches × 16 inches, bolted together in pairs, with horizontal walings and cross bracing. This viaduct is illustrated in Haskoll's *Examples* above mentioned, as is also a small timber viaduct on the Lynn and Ely Railway, which consists of five spans of 31 feet, framed in a manner similar to that of the bridge over the Brenta, *Plate* XXXVI., *fig.* 3. The piers consist of rows of single piles, eight in number, 12 inches × 12 inches; the main timbers of the truss are 12 inches × 10 inches; the ends of the struts and straining-beams are let into cast-iron sockets.

LEVEL CROSSING GATE.

305.—When a railway crosses a public road, a bridge is generally made if there is much difference of level; the railway either passing over or under the bridge, according to their relative levels. It often happens, however, that the two roads are nearly on the same level, in which case it becomes necessary to allow the traffic of the road to cross the railway itself without a bridge; and, to prevent accidents, a gate is placed on each side of the railway. *Plate* XLVIII. represents the plan, elevation, and details of a level crossing gate, of timber, which may be taken as a type of those in general use on most railways.

A signal-box is often placed near one of these gates, and it is the duty of the signal-man to see that the gate is closed on the approach of a train. The closing and opening of the gate is often effected by means of a set of levers communicating with a wheel in the signal-box, so that it can be opened and closed therefrom without the necessity of the signal-man leaving his box.

SECTION IX.

ON SCARFS, JOINTS, STRAPS, BOLTS, SHOES, AND SOCKETS.

306.—THE joints of timber-framing having to support whatever strains the pieces joined are exposed to, should be formed in such a manner that the bearing parts may have the greatest possible quantity of surface; provided that surface be made of the best form for resisting the strains.

For should that part of the joint which receives the strain be narrow and thin, it will of course either indent itself into the pieces to which it is joined, or become crippled by the strain: and whichever of these happens, a change must be produced in the form of the framing.

The effect of the shrinkage and expansion of timber should also be considered in the construction of joints. On account of the shrinkage of timber, dovetail joints should never be used in carpentry, as the smallest degree of shrinking allows the joint to draw out of its place; and, consequently, it loses all its effect in holding the parts in their proper situation. Dovetail joints can only be used with success when the shrinkage of the parts counteract each other: a case which seldom happens in carpentry, but is common in joinery and cabinet-making.

Joints should also be formed so that the contraction or expansion may not have a tendency to split any part of the framing. The force of contraction or expansion is capable of producing astonishing effects where the pieces are confined, and may sometimes be observed in framing which has been wedged too tightly together in improper directions. The powerful effect of expanding timber is well known to quarry-men, as they sometimes employ its force to break up large stones.

In forming joints, the object to be attained should always be kept in view, as that which is excellent for one purpose may be the worst possible for another. This consideration then must guide us in the division of this section, which will be considered under the following heads:—

First.	Of lengthening pieces strained in the direction of their length.
Secondly.	Of lengthening pieces exposed to cross strains; and building beams.
Thirdly.	Of lengthening beams having to resist compression.
Fourthly.	Of joints for framing.
Fifthly.	Of joints for ties and braces; and
Sixthly.	Different methods of connecting the parts of joints.

I.—ON LENGTHENING PIECES OF TIMBER WHICH ARE TO RESIST STRAINS IN THE DIRECTION OF THEIR LENGTHS.

307.—The simplest, and perhaps the best, method of lengthening a beam is to abut the ends together, and to place a piece on each side; these, when firmly bolted together, form a strong and simple connection. Such a method of lengthening a tie is shown by *fig.* 4, *Plate* XLV., and is what ship-carpenters call *fishing* a beam. It is obvious, however, that the strength in this case depends on the bolts, and the lateral adhesion and friction produced by screwing the parts tightly together.

The dependence on the bolts may be much lessened by indenting the parts together, as shown by the upper side of *fig.* 5; or by putting keys in the joint, as shown by the lower side of same figure; but the strength of the beam will be lessened in proportion to the depth of the indents.

The only reasons for not depending wholly on bolts are, that should the parts shrink ever so little, the bolts lose a great part of their effect: and the smallness of the bolts renders them liable to press into the timber, and thus to suffer the joint to yield.

The sum of the areas of the bolts should never be less than two-tenths of the area of the section of the beam; and it is not a good practice to put bolts near to the ends of the pieces.

308.—The usual method of joining beams is that called *scarfing*, where the two pieces are joined so as to preserve the same breadth and depth throughout; and wherever neatness is preferable to strength, this method should be adopted.

From *fig.* 6 to *fig.* 13 various methods of scarfing are shown. The first (*fig.* 6) is the most simple; it depends wholly on the bolts, and in this and like cases it is best to put a continued plate of iron on each side for the heads of the bolts. The ends of the plates may be bent and let into the beams.

Fig. 7 is another very common, but not so good a combination, as the bolts do not press the surfaces in a perpendicular direction; and an oblique pressure, such as will have place in this example, must have some tendency to separate the joint, without any advantage in other respects.

Fig. 8 is a joint that would do without bolts, but it is clear that the strength would not be quite so great as half the strength of an entire piece; the key, or double wedge, at *a*, should only be driven so as to bring the parts to their proper bearing, as it would be better to omit it than to drive it so as to produce much constant strain on the joint. It is not necessary that there should be a key, except when bolts are to be added, and then it is desirable to bring the joints to a bearing before the bolts are put in. The addition of bolts and straps makes this an excellent scarf.

Fig. 9 is a slight modification of the last described scarf, where the keys are supposed to be of hard wood; if of a curled grain, so much the better. In this form the scarf is easier to execute, and equally as good as the last, when bolts are used.

Fig. 10 represents a very common form, and a very good one, but it appears to be inferior to the two preceding ones (*figs.* 8 and 9); and it is much more difficult to make a sound joint of this form.

When bolts are added—and they are always necessary in pieces exposed to considerable strains—the scarf represented by *fig.* 11 is a very good and strong form for a scarf.

Fig. 12 differs from the last only in having keys instead of being tabled together.

Fig. 13 represents a scarf where the oblique joints in the last examples are avoided, and the same degree of strength is obtained; at the same time it is very simple and easy to execute.

To determine the length of a scarf, in joining beams, it is necessary to know the force that will cause the fibres of timber to slide upon each other. The researches which have been made on this subject have already been laid before the reader in Section II., Arts. 110 and 111. To apply them to our present object, let AB, *fig.* 1, *Plate* XLVI., be part of a scarfed beam, strained in the direction of its length, and put together without bolts. Now it is plain that the strength of the part $c\,b$ must be exactly equal to the force that would cause the fibres to slide at the dotted line $c\,d$; for, if the part $c\,d$ were shorter, the joint would not be so strong as it is possible to make it. Also, if the depth of the indent $a\,c$ be too small, it would be crushed by the strain; consequently the parts must have a certain proportion, so that the joint may be equally strong in each part.

In the first degrees of extension and compression the resistance is equal, therefore the depth of the indent $a\,c$ must be equal to the part $c\,b$, in order that the strain may be equal; and it is evident, that when there is only one indent, as in this example, the depth $a\,c$ should be one-third of the whole depth. Also, let d be the depth of the beam, and m the number of indents; then $\frac{d}{3m}$ = the depth of each indent. Or the sum of the depths of the indents must be equal to one-third of the depth of the beam.

To determine the length of the part $c\,d$, we must know the ratio between the force to resist sliding and the direct cohesion of the material. Let that ratio be as $1 : n$; then $c\,d$ must be equal n times $c\,b$; that is, in oak, ash, or elm, $c\,d$ must be equal to from 8 to 10 times $c\,b$.

In fir, and other straight-grained woods, $c\,d$ must be equal to from 16 to 20 times $c\,b$.

Hence may be derived some maxims that will be sufficiently accurate for practical purposes.

1.—In oak, ash, or elm, the whole length of the scarf should be six times the depth or thickness of the beam, when there are no bolts.

2.—In fir the whole length of the scarf should be about twelve times the thickness of the beam, when there are no bolts.

3.—In oak, ash, or elm, the whole length of a scarf depending on bolts only, should be about three times the breadth of the beam; and for fir beams it should be six times the breadth.

4.—When both bolts and indents are combined, the whole length of the scarf for oak and hard woods may be twice the depth; and for fir, or soft woods, four times the depth.

II.—ON LENGTHENING BEAMS INTENDED TO RESIST CROSS STRAINS, AND BUILDING BEAMS.

309.—Beams to resist cross strains require to be lengthened more frequently than any others; and from the nature of the strain, a different form must be adopted for the scarf from that which is best for a strain in the direction of the length. There are cases where beams are exposed to both strains at the same time, but the cross strain is generally that of the most importance. Of this we have an example in the tie-beam of a roof, where the strain in the direction of the length is very small compared with the cross strain.

Let CD, *fig.* 2, *Plate* XLVI., represent a beam strained by a load at E, and supported at the ends. All the parts above the middle of the depth, *b c*, will be compressed, all below will be extended: therefore the square abutment *a e* is better for the upper side than any complicated joint whatever: and it is evident that all oblique joints should be avoided on the compressed side. In this figure the whole of the strength of the lower side depends on the bolts and strap.

Fig. 3 shows another form, where the lower or extended side is indented so as not to depend wholly on the strap and bolts; and a key is introduced to tighten the scarf. It will readily appear, that had the joint been cut to the dotted line instead of the oblique line, the strength would have been much impaired.

Fig. 4 is another form with some slight alterations.

Fig. 5 represents an angular view of a scarf where it is jointed the contrary way. An iron plate at *a b c d* is supposed to be removed, which shows the tongue at *e*. This method appears to employ more of the strength of the timber than any other, and is very well adapted for a tie-beam where it is strained both across and in the direction of its length.

In all these cases the depth of the indents, and the length of the scarf, will be obtained by the same rules as for beams strained in the direction of their length. (See Art. 308.)

In scarfing beams to bear a cross strain, it would be a great advantage to apply hoops or straps instead of bolts, as the coachmakers and ship-carpenters do. It would be easy to form the scarf so that hoops might be driven on perfectly tight.

There is no part of carpentry which requires greater correctness in workmanship than scarfing; as all the indents should bear equally, otherwise the greater part of the strength will be lost. Hence we see how very unfit some of the complicated forms shown in the old works on carpentry were for the purpose. It is certainly very absurd to render the parts difficult to be fitted, when the whole of the strength depends on their fitting well. "But many," says Professor Robison, "seem to aim at making the beam stronger than if it were of one piece; and this inconsiderate project has given rise to many whimsical modes of tabling and scarfing."

ON BUILDING BEAMS.

310.—The manner of building beams has already been considered in Section III., Art. 145; but it may not be superfluous to remark here, that the position of the indents

is not a matter of indifference. If two plain pieces were laid upon one another, and supported at the ends, the pressure of a weight applied in the middle would cause them to bend, and the touching surfaces would slide against one another; the upper piece sliding towards each end upon the lower one. This sliding is effectually prevented by indenting the surfaces, as is shown in *fig.* 6, *Plate* XLVI., when the pieces are bolted together; but if the same indents be reversed, as in *fig.* 7, they produce scarcely any effect, and nearly the whole strain is upon the bolts.

Wherever the principal strain on the beam may happen to be, to that point, as at C, *fig.* 6, the indents should direct the square abutments; that is, towards the straining force. When the beam is uniformly loaded, the greatest strain is at the middle.

We have often seen, in drawings, all the indents put the same way, and sometimes as in *fig.* 7; otherwise the preceding remarks would have appeared to have been unnecessary.

If the depth of the indents be too small in a built beam, they will not be capable of resisting the pressure; and if they be made too deep, the number of fibres will be diminished, and consequently the strength of the beam; therefore there is a depth for the indents by which a maximum of strength will be gained. Duhamel undertook to ascertain the proper depth by experiment;* and the general rule we have given in Art. 145, Section III., agrees extremely near with the case he tried.

III.—ON LENGTHENING BEAMS THAT ARE INTENDED TO RESIST COMPRESSING FORCES.

311.—When a post or strut is required to be longer than timber can be procured, as sometimes may occur in the construction of wooden towers, spires, wooden bridges, or centres, the same form of joint or scarf is applicable as when the piece is pulled in the direction of its length, with this difference, that there must not be any inclined or oblique parts in the scarf.

Figs. 6, 8, 9, and 13, of *Plate* XLV., and *figs.* 1 and 5 of *Plate* XLVI., will answer equally well for posts or ties, only it would be better to tongue the ends, as at *e*, *fig.* 5.

In *fig.* 4, *Plate* XLV., a piece on each of the four sides will be necessary, unless some other mode of strengthening it should form a part of the framing to which it is to be applied. It is not a very neat method of piecing a strut, but is one that is very convenient, especially in temporary structures, such as centres, where it may generally be braced in one direction, and where a more laboured form of joining would be much out of place.

IV.—ON JOINTS FOR FRAMING.

312.—*Of Joints for bearing purposes.*—The joint of a binding joist into a girder is an example of this kind of joint. The greatest strains upon the fibres of a girder are at the upper and lower surfaces, and the strain gradually decreases towards the middle of the depth, where it becomes insensible; hence the most suitable place for a mortise is at the middle of the depth.

* *Transport des Bois.*

The upper side being compressed, it is imagined by some writers that the tenon might be made to fit so tightly that the strength of the girder would not be impaired by it: but this is a mistake; for any one who knows anything of the practice of carpentry, knows that it cannot be done in an effectual manner: besides, the shrinkage of the joist would soon render it loose, however tightly it might be fitted in the first instance.

Considering then that the best place for a mortise in a girder or other beam in a like position is at the middle of its depth, the next point is to consider the best place and form for the tenon.

If the tenon be near the lower side, it will evidently have the advantage of employing most of the strength of the joists; but this, on account of the strength of the girder, cannot be adopted; therefore the form in general use represented in *Plate* IV., *fig.* 46, appears to combine all the advantages required. The tenon being one-sixth of the depth, and placed at one-third of the depth from the lower side.

Binding joists, or any other beams in a like position, should never be made with double tenons; for, as Mr. Price has judiciously remarked, it weakens the timber framed into it, and both tenons seldom bear alike: besides, in pinning, it rarely happens that there is a draft on both tenons, unless the pin be as tough as wire.*

All horizontal timbers for bearing purposes should be notched upon the supports rather than framed between, whenever it can be done, as much additional strength is gained by preserving timbers in continued lengths. The same observation applies to inclined timbers, such as common rafters. (See Section II., Art. 94.)

313.—*Of the Joints of Framing.* The object to be obtained by a system of framing, is to reduce all the pressures into the directions of the lengths of the pieces composing the frame; therefore the form of the joint should be made so as to direct the pressures into the axes of the pieces. As when the direction of the strain does not coincide with the axis of the piece strained, the strain will be much increased. Now, from the form of the joints sometimes employed, it must generally happen, that by shrinkage, or settlement, the pressure will bear only upon the angular points of the joint; which not only gives a considerable leverage to the straining force, but also, by the whole bearing being upon an angle, that angular point must be either indented or crippled by the strain, which of course causes a further settlement. The extent of the evil of partial bearings becomes very manifest when the strains are considerable. In the centres of the Bridge of Neuilly seven or eight pieces in each frame were split from end to end, and many others bent considerably; and in these centres the joints were not very oblique, otherwise the effects would have been more serious. Perronet was sensible of the cause, and in order to correct it he formed the abutments according to an arc of a circle, of which the other extremity of the piece was the centre.

This method was adopted for the joints of the centre for the Bridge of Sainte Maxence, and also in that for the Bridge de la Concorde, at Paris; and it was effectual in preventing the splitting and bending of the pieces.† The principle, however, was not new, as it had been recommended by Serlio for the joints of stone columns.‡

Circular abutments have been strongly recommended by Professor Robison, and they

* *British Carpentry*, Introduction.

† Gauthey, *Construction des Ponts.*

‡ Serlio's *Architecture*, Paris, 1545.

certainly might be employed with much advantage. The principle is similar to the well-known contrivance called the ball and socket; and to the joints of animals, where, with considerable latitude of motion, uniformity of pressure is preserved. That they require more labour, there is no doubt; but were the labour doubled, it would be comparatively a trifling object in a framing of importance; and for any other purpose it is not recommended.

It is obvious, that when the one end of the piece moves, a corresponding movement will take place at the joint; and when the radius of curvature at the joint is small, as it is in the joints of animals, the motion of the joint will scarcely be perceptible. For in a roof of 30 feet span a sinking of 6 inches in the middle would not cause the joints to slide more than $\frac{1}{10}$ of an inch.

314.—We may now proceed to notice some of the joints of most common occurrence, and point out the advantages to be obtained by altering the forms of them.

When one piece is perpendicular to another, as for example, a post upon a sill, the most usual, as well as the most easy method, is to make the joint square, with a short tenon of about one-fourth of the thickness of the framing, to retain it in its place.

But if the joint be not very accurately cut, the whole load will bear upon the projecting parts; consequently, the centre of pressure will seldom coincide with the axis of the post, and its power to resist pressure will be much lessened. (See Section II., Art. 127.)

If, instead of cutting the joint square, it were cut to form an angle, as it shown by *fig.* 8, *Plate* XLVI., then a very little care in cutting the joint would make the centre of pressure coincide with the axis.

Now, whether the joint be square or angular, a slight inclination from the perpendicular will throw the pressure upon one corner; but if the joint be described from a centre situate in the axis, and with a radius not much greater than half the breadth of the post, as is shown in *fig.* 9, then, with any change of position, the joint will slide till the pressure is uniform upon the joint; and if the joint be moderately well made, the pressure will not act with any sensible leverage upon the post. It has been shown, however, by Mr. Hodgkinson that in *long* pillars the resistance to fracture by flexure is about three times greater when the ends are flat and firmly bedded, than when they are rounded and capable of turning. The ratio is less than this in *short* pillars.*

315.—When the pieces to be joined are not at right angles to one another, the joints may be of two kinds; the principal rafter of a roof affords an example of each. Before proceeding to show the nature of these joints, it is necessary to state, that the direction of the strains, as well as their magnitude, as determined by the principles laid down in Section I., remain sensibly the same, whatever may be the form of the abutting joints, except in as far as the form of the joint alters the points of bearing; which may in some cases cause the pressure to act with a leverage nearly equal to half the depth of the beam. The strength of the joint itself depends upon its form, as it may be so made that there will be a tendency to slide, which it would be well to avoid without having recourse to straps.

The resistance at the joint is always most effectual when the abutment is perpendicular to the strain; but where the angle formed by the inner sides of the pieces is very acute, this kind of abutment cannot be obtained, at least not without wounding the tie too much.

Let ABC, *fig.* 10, *Plate* XLVI., be the joint of a principal rafter upon the tie-beam; where

* *Philosophical Transactions*, 1840, and Barlow's *Strength of Materials*.

the dotted line AB shows the direction of the straining force, and B*a* is one of the abutting surfaces. Draw *a c* perpendicular to B*a*; then, by the principles of the resolution of forces (Section I., Art. 26), *c a* will represent the force pressing on the inclined part B*a* of the joint, and there will remain a force represented by B*a* to be sustained by the abutment B*d*. And as this abutment will resist the force most effectually when it is perpendicular to it, therefore B*d* should always be perpendicular to B*a*: the same will be true in whatever direction the straining force acts.

Fig. 10 shows one of the most common joints: B*a* and B*d* are the abutting surfaces, which are to be perpendicular to each other; and *b e* shows the tenon, the thickness of which may be about one-fifth of that of the framing. This joint might always take better hold of the tie-beam than it is generally made to do, without any risk of weakening it. In general, B*d* should somewhat exceed half the depth of the rafter, and the joint should be left a little open at *a*, in order that it may not be thrown off at B, by the settling of the roof.

Fig. 11 is a form which is approved by some authorities, but by others it is considered inferior to the one already described. The dotted line shows the form of the tenon; but it would be better put together in the same manner as the joint to be next described.

Fig. 12 is a very good form for a joint, as *b d* is perpendicular to the strain, considering the strain to be in the direction of the rafter, which is near enough to the truth for our present purpose. The best method of forming this joint is shown by the projected sketches A and B; as by this method it is easy to see when they are accurately fitted; whereas in a mortise-and-tenon joint this cannot be done, and they are often very imperfectly fitted, because it is easy to conceal any defect.*

Fig. 13 shows a joint with a curved abutment; the line BA represents the direction of the strain; and *c* the centre, which should be in this line. The radius for describing the joint should be greater than half the depth of the rafter; and the part between *a* and *b* of the joint should be left open to admit of any degree of settlement that may take place. The projected sketches, C and D, show the manner of forming the joint. From the experiments of Mr. Hodgkinson it would appear that this form of abutment has a tendency to weaken the rafter (Art. 314).

Sometimes double abutments are used in joints, but it requires both great accuracy in workmanship, and also that the roof should not settle more or less than the workman allows for, in order to make both abutments bear equally; for which reason one good abutment appears preferable to two. Professor Robison very justly remarks, that "because great logs are moved with difficulty it is very troublesome to try the joints frequently to see how the parts fit; therefore we must expect less accuracy in the interior parts. This should make us prefer those joints whose efficacy depends chiefly on the visible joint."† But to make double abutments still further increases the difficulty, without adding anything to the security of the joint.

316.—The joint at the upper end of the principal rafter differs from that of the lower end in some respects; but the difference is not material in respect to the principle of forming the joint. Making the king-post larger at the head enables us to get a more effectual

* Joints of this kind are described by Ware, in his *Complete Body of Architecture.*

† *Encyclopædia Britannica*, Art. "Carpentry."

abutment; and this abutment should be, in common joints, square to the back of the rafter, as at A, in *fig.* 2, *Plate* XLVII., with a short tenon, shown by the dotted lines. When the head of the post is not sufficiently large to get the abutment square to the back of the rafter, it is usual to cut it as at B. In either case the joint should be left a little open at *a*; so that when the roof settles it may not bear upon the acute angle.

The same remarks will apply to all similar joints; such, for example, as the joints between the braces or struts and king-post at C and D, *fig.* 2.

But the joints D and B would be better formed in the manner shown at A and B, *fig.* 4, where *a b* is at right angles to *b c*. The reason for this form is given in Article 315, with reference to *fig.* 12, *Plate* XLVI. The joints may be made as shown by the projected sketches E and F.

A joint with a curved abutment is shown by *fig.* 5, *Plate* XLVII.: BC represents the middle of the depth of the rafter, and *c* the centre from which the curve is described; the radius C*c* should not be less than half the depth of the beam; A and D are projected sketches of the joint.

In *fig.* 5, E shows a joint for the straining-beam of a roof, and G is a projected sketch of the joint. As a further security, the piece F might be nailed upon the queen-post C. The same objection, however, exists to curved joints in this part of the framing as was mentioned at end of Article 314, the strength of the rafters and straining beam being reduced thereby. The lower part of *fig.* 5 shows the joint for struts or braces.

317.—Instead of the common method of framing the king- or queen-posts between the ends of rafters and the like, it is much better to make the rafters abut against one another, end to end; and to notch a piece on each side, and bolt through these pieces. These may be called *suspending pieces*, because they serve to suspend the tie-beam. (The term post is ridiculous, because it conveys a false notion of the office of the piece; but it is difficult to change a term in common use.) *Figs.* 6 and 7, *Plate* XLVII., show this method of joining. It has been long in use for centres, bridges, and roofs, as may be seen in the plates of the Bridge at Schaffhausen, the Bridge of Ritter, near Berne,* the roof of the Riding House at Moscow (*Plate* XXI.); and in some very good roofs executed in this country.

The German carpenters, and many others, put a piece of lead between the abutting surfaces of their joints, in order to equalise the pressure. This method is not, however, so useful in timber-work as it is in stone-work: a plate of cast-iron between the abutting surfaces would perhaps be preferable.

V.—ON JOINTS FOR TIES AND BRACES.

318.—There is no part of carpentry where defective joints are attended with such serious inconveniences as the joints of ties, nor are there any other joints so often ill-constructed. It is not easy to make a good tie joint, from the very nature of timber, and therefore many ties should not be used where it is possible to avoid them. It has been before stated, "that dovetail

* Rondelet, *L'Art de Bâtir.*

joints should never be used in carpentry" (Art. 306), and the maxim cannot be too strongly urged wherever the joint is intended to hold parts together.

For let A, *fig.* 14, *Plate* XLVI., represent the angle of a building, where the wall-plates are joined by a dovetail joint; the part *a b*, being the crossway of the wood, will shrink in drying; and as the other piece is the lengthway, its shrinkage will be insensible; therefore a very small degree of shrinkage will allow the joint to draw considerably, as is shown by the dotted lines, and it acts with the power of a wedge to force out the end of the piece. A joint made as shown in *fig.* 15 avoids any danger of giving way from the shrinking of the timber, and is better than any dovetail joint whatever.

Dovetail joints, or dovetail tenons, have been used in various parts of carpentry, such as the collar-beam of small roofs, the lower end of king- and queen-posts, and for joining-plates and the like. In all these cases they are the worst kind of joints that can be used. The *carpenter's boast* must also be classed as a dovetail joint equally as defective as any.*

Fig. 3, *Plate* XLVII., shows a method of notching a collar-beam, C, into the side of a rafter, R, which is far superior to a dovetail joint.

A stout pin, of tough but straight-grained oak, is an excellent addition to a tie joint, and is more economical than an iron bolt. The excellence of wooden pins is fully shown by their extensive use in ship carpentry, as they form the chief connection of ship-timbers, under the denomination of tree-nails.

VI.—ON CONNECTING THE PARTS OF JOINTS.

319.—The parts of joined pieces may be connected by wooden pins, by nails, by screws, or by straps. The cases where adhesive matter may be applied are few and unimportant, as the settlements and change of bearing of joints through shrinkage and deflection renders such applications useless in carpentry; while in joinery they are resorted to for almost all joints.

WOODEN PINS. The connection of joints by wooden pins is an old and effective method, which still continues to be the best known for various purposes. The section of the pin should be at least equal to resist the strain tending to break it directly across (see Art. 110): and where pins are draw-bored for the purpose of drawing joints close, the flexure of the pin in the bore should be less than that which gives it a set curvature; otherwise the strain on the pin will be too great. Tough and hard wood makes the best pins.

ON CAST-IRON SHOES.

320.—A practice has been recently introduced into the construction of roofs having the beams of wood, of protecting their extremities from the damp, and consequent decay to which

* The "carpenter's boast" is shown on *Plate* 40, *fig.* A, of Nicholson's *Carpenter's New Guide.* Crosby Lockwood & Co.

they are liable by resting immediately in contact with the brick or stonework of the walls of the building. This is effected by what the workmen call cast-iron shoes, which are attached to the ends of the tie-beams by means of bolts, nuts, &c.

The iron shoe itself of course takes various forms, according to the circumstances and situation where it is introduced, and the particular views of the architect who employs it.

Figs. 35 and 36 show the form of iron shoe introduced into the roof over the iron foundry of the Butterly Iron Works, in which the tie-beam is of wood, but the other parts of iron. The shoe, as will be seen by the figures, has a step for the end of the cast-iron rafter, which is bolted to it, and a recess for a large screw-bolt, which passes down through the side wall.

FIG. 35.

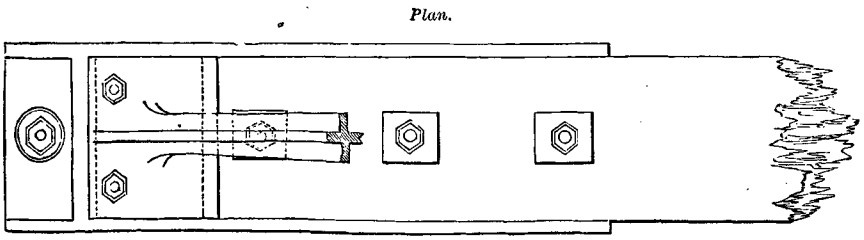
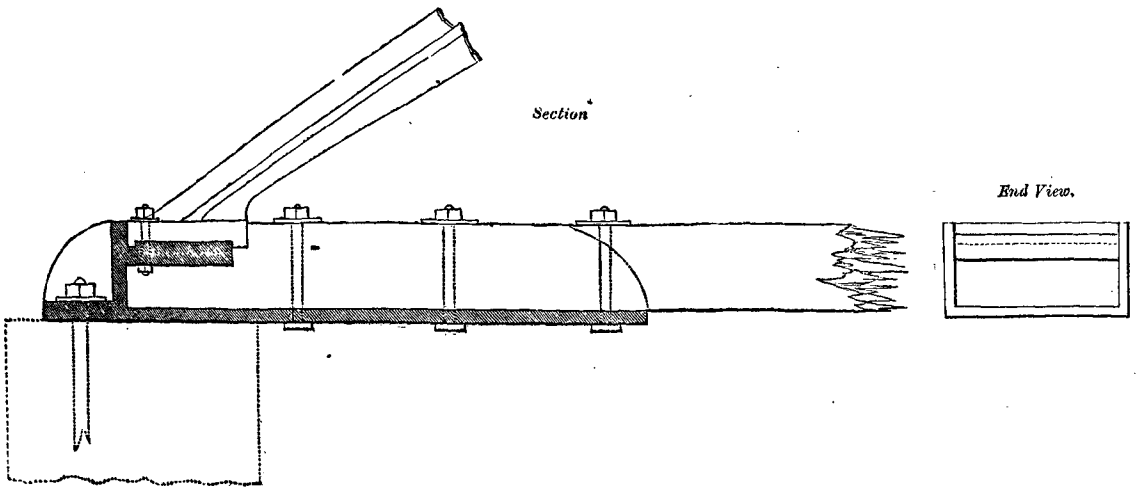


FIG. 36.



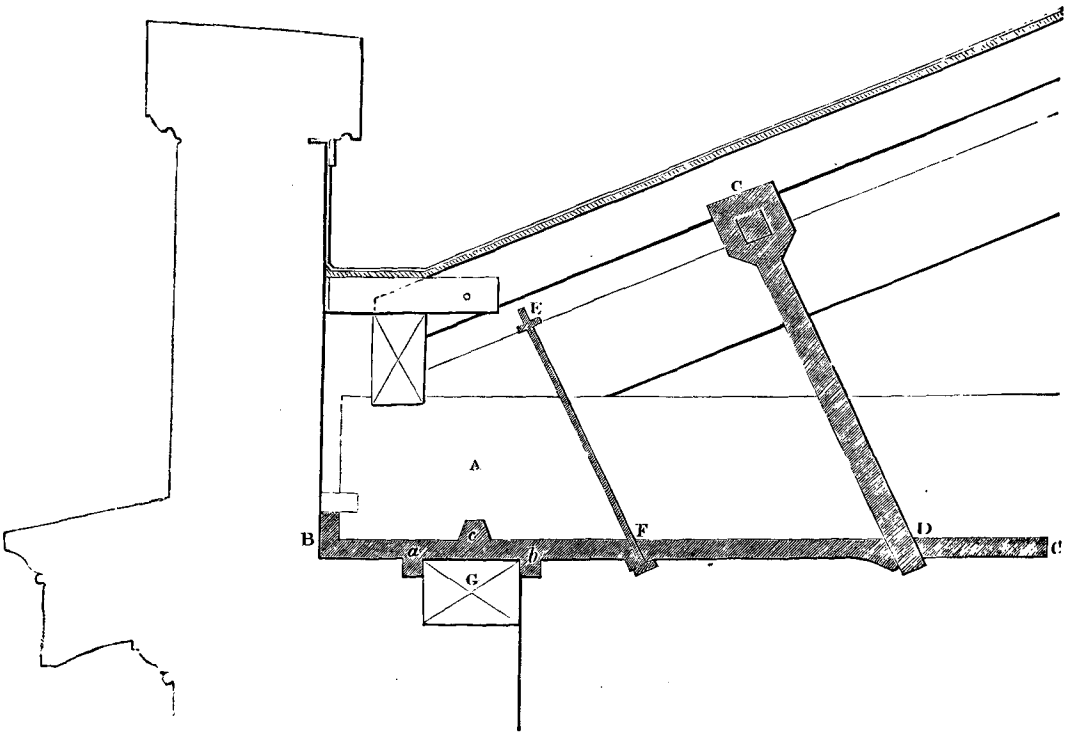
In such a case as this, where, from the nature of the work carried on, every part is exposed to great heat and moisture, the defence afforded by such an attachment is of great importance—the wood, unless thus protected, being of course very liable to decay in those parts where damp and moisture might accumulate.

Another form of cast-iron shoe will be seen by referring to *Plate* XVIII. This is employed in the timber roof over the hall of Christ's Hospital. It is very complete in its form, and

affords an obvious and perfect protection from the damp, and consequent decay, to which the ends of the beams would be liable if placed in immediate contact with the stone and brickwork of the building. It would be useless to give a great variety of examples of this kind of attachments, their particular forms being by no means a matter of importance. We shall content ourselves, therefore, with giving one or two other cases exhibiting very simple forms of shoes.

In *fig.* 37, A is the tie-beam; BC the cast-iron shoe; CD an iron strap; EF a screw-bolt; and G the wall plate; *a*, *b*, projections on the shoe to embrace the wall plate; and *c* a similar projection let into the beam itself. It will be seen that by this simple form of shoe the

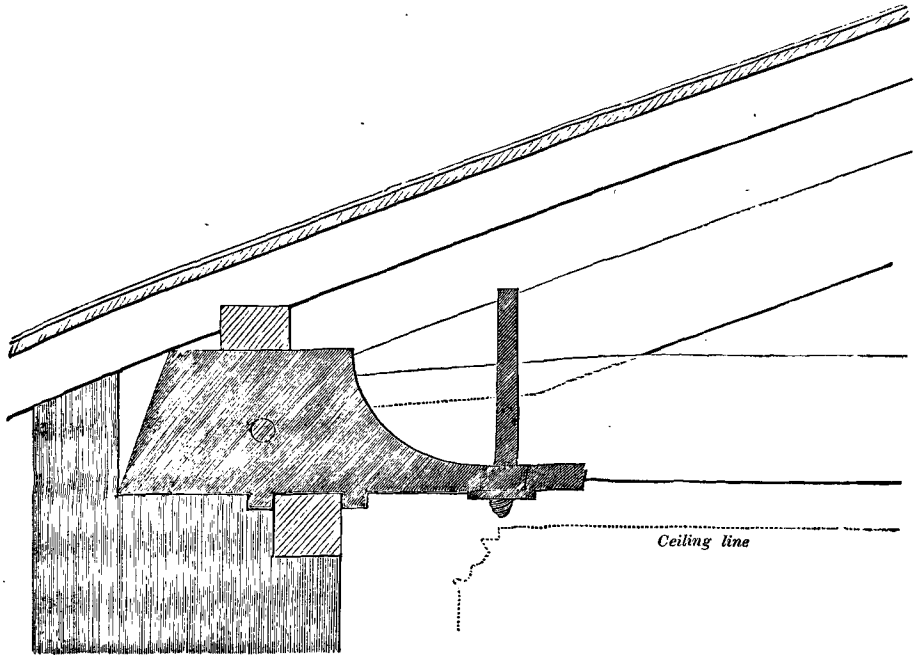
FIG. 37.



tie-beam is protected entirely from contact with the wall, and consequently from that liability to decay which it is the object of this contrivance to effect.

Another kind of cast-iron shoe is exhibited in *fig.* 38, as erected at Stamford Street Chapel, Blackfriars, from the design of Mr. C. Parker. The form is sufficiently illustrated in the figure. Its dimensions are—length, 3 feet 2 inches, and width, 6 inches; it is connected with the tie-beam by an iron strap, 2 inches wide, which passes over and secures the foot of the principal rafter; and while it thus protects from decay that part of the beam which would otherwise rest on the brickwork, its extension acts as a corbel, and thereby strengthens the construction of the truss.

FIG. 38.



CAST-IRON TIE-BEAM PLATE. A similar object is sometimes attained by what is called a tie-beam plate. At the banking-house of Messrs. Hoare, Fleet Street, a plate of this kind is introduced. It is 7 inches wide, and $2\frac{1}{2}$ inches deep, placed under the tie-beam, forming thus a corbel, and protecting from decay those portions of the timber which would otherwise rest on the wall.

It possesses most of the advantages of the entire shoe, and is particularly applicable to the usual circumstances where wood or stone corbels are applied, being formed in the depth required for the ceiling joists. It is secured to the framing in three places; so that should any portions of the wood decay, a failure need not be apprehended. Thus, by a return piece of the plate let into the beam, it is fixed at one end, while an inch twist screw-bolt from the back of the rafter holds it in the middle, and, by being connected with the strap which unites the principal and tie-beam, it cannot move from its place at the extremity.

An iron shoe is sometimes fixed on the top of the tie-beam to receive the foot of the rafter, as shown in the roof-truss on *Plate* VIII., *fig.* 1. A cast-iron shoe is also used to receive the lower ends of the struts in the truss of the St. Germains Viaduct, *Plate* XLV.

ON CAST-IRON SOCKETS.

321.—Instead of framing the heads of rafters and ends of straining-beams into the heads of king- or queen-posts, as described in Article 316, the practice has become a common one of letting them into a cast-iron socket; an example of which for a king-truss

is shown on *Plate* VIII., *fig.* 1, and also on *Plate* XVI. Examples of the use of sockets for a queen-truss are given in *fig.* 2, *Plate* VIII.; the roof of Christ's Hospital, *Plate* XVIII.; and the roof of the goods station of the Great Northern Railway terminus, *Plate* XIX. The advantage of this arrangement is the prevention of all shrinkage at the joints from framing one piece into the head of another. When an iron socket is used in the manner above stated, the timber king or queen is replaced by a wrought-iron tie-rod which passes through the socket, on which its head rests, and also through the tie-beam with a screw-nut and plate on the underside, by means of which the framing can be screwed up tightly, and any amount of camber given to the tie-beam.

Cast-iron sockets are sometimes used where the head of an inclined strut abuts against a horizontal beam as shown in the details of the St. Germains Viaduct on *Plate* XLIV.

ON STRAPS, BOLTS, ETC.

322.—"A skilful carpenter," says Professor Robison, "never employs many straps, considering them as auxiliaries foreign to his art;" and indeed they are seldom necessary, except to suspend the tie-beam to the king-post, and to secure the feet of the principal rafters to the tie-beam of a roof.

Strap for King- or Queen-Post.—In *fig.* 2, *Plate* XLVII., *s* shows a strap for suspending the tie-beam to a king- or queen-post: its hold of the post may be improved by turning the ends, as at *d d*, in the section E: these, when well fitted, will, with the addition of bolts, give the strap a firm hold; or staples, as in *fig.* 4, may be used for a slight roof. The strengths of straps for different bearings are stated below. When the longest unsupported part of the tie-beam is

10 feet, the strap may be 1 inch wide by $\frac{3}{16}$ inch thick.
15 „ „ „ $1\frac{1}{2}$ „ „ $\frac{1}{4}$ „ „
20 „ „ „ 2 „ „ $\frac{1}{4}$ „ „

These dimensions are quite sufficient for common purposes; but where the machinery of a theatre, or other heavy load, is to be borne by the tie-beams, the straps must be made stronger in proportion to the load; the tensile strain that wrought iron will bear with safety being 5 tons per square inch of section.

Where suspending pieces are used instead of queen-posts, the same kind of strap will apply, as is shown in *fig.* 6. In order to enable the carpenter to lighten up the truss, a slot is formed in the top of the strap through which key wedges can be driven, as shown on *Plate* XVI.

323.—*Strap at the foot of a principal Rafter.*—A strap at the foot of a principal rafter is intended to form an abutment for it, in case the end of the tie-beam should fail. If the strap be put too upright it will, instead of forming an abutment, become quite loose when the roof settles; and as it is intended to prevent the rafter-foot sliding along the tie-beam, an oblique position, as shown by *fig.* 11, *Plate* XLVI., and *fig.* 1, *Plate* XLVII., will be the most effectual. In large roofs, longer straps with more bolts will be required. Straps of the

same size as are used for the king-post will be sufficient. In bolting on straps, they ought to be drawn tight; Mr. Price recommends square bolts for this purpose; he says, "for this reason, if you use a round bolt, it must follow the augur, and cannot be helped; but, by helping the augur-hole, that is, by taking off the corners of the wood, you may draw a strap exceedingly close, and at the same time it embraces the grain of the wood in a much firmer manner than a round pin."

Sometimes a bolt is used, put through square from the back of the rafter, with cross plates at the head and nut. *Fig.* 10, *Plate* XLVI., shows this method, the dotted lines representing the bolt. In the truss on *Plate* XVI. a vertical bolt is passed through the rafter and tie-beam, and an inclined strap is used as well with slot for key wedges to tighten up the joint.

324.—It must be remembered, that thin plates of iron decay very rapidly, particularly in damp situations; therefore they should be well secured against rust, by being painted as soon as they are made. Mr. Smeaton, writing on this subject, says: "I had observed, that when iron once gets rust, so as to form a scale, whatever coat of paint or varnish is put over this, the rust will go on progressively under the paint." The method he used to prevent iron rusting, was to heat the whole of the iron-work to about a blue heat, and immediately strike it over the surface with raw linseed oil; the next day, if properly done, it appears as if a coat of varnish had been laid on. By this method the pores of the iron become filled, and effectually protected from corrosion.

Another method, which is usually applied to small articles, consists in heating the metal, and rubbing it over, while hot, with wax. By this process the iron acquires an extremely uniform coating. The process of galvanising or coating the iron with zinc is the best and most durable method of preventing rust that has yet been employed.

325.—BOLTS of wrought-iron are used for holding the straps at the feet of the rafters and of the king- and queen-posts, being provided with a fixed head at one end and a screw and nut at the other. They are also employed in place of timber for the king- and queen-posts of a truss, as shown in *Plates* VIII., XVI., and XVIII., the nut being screwed up under the tie-beam; and to prevent injury to the wood, a *washer*, or flat piece of iron, is placed between the nut and the timber so as to distribute the pressure. For a roof in which the longest unsupported part of the tie-beam is 10 feet, a king-bolt 1 inch diameter will be of ample strength; and for 20 feet, one of $1\frac{1}{2}$ inches diameter may be employed. Bolts are also used to hold the rafter to the tie-beam, as mentioned above in Article 324. The use of bolts in scarfing has been described in Articles 306 to 310, in which, however, the strain is transverse or *shearing*.

326.—NAILS. Nails are, in fact, pins made of iron, and the resistance they offer to being drawn is very considerable.

The following abstract of Mr. Bevan's experiments exhibits the relative adhesion of nails of various kinds, when forced into dry Christiana deal, at right angles to the grain of the wood.

Kind of Nails.	Number to the pound avoirdupois.	Inches long.	Inches forced into the wood.	Pounds required to extract.
Fine sprigs	4,560	0·44	0·0	22
,, ...	3,200	0·53	0·44	37
Threepenny brads	618	1·25	0·50	58
Cast-iron nails	380	1·00	0·50	72
Sixpenny nails	73	2·50	1·00	187
,, ,, ...	...	...	1·50	327
,, ,, ...	...	...	2·00	530
Fivepenny	139	2·00	1·50	320

The force required to draw the same sized nail from different woods averaged as under:—

Kind of Wood.	Weight in lbs. required to draw a sixpenny nail driven in one inch.
Dry Christiana deal	187 lbs.
Dry oak	507 ,,
Dry elm	327 ,,
Dry beech	667 ,,
Green sycamore	312 ,,
Dry Christiana deal, driven in endways	87 ,,
Dry elm, driven in endways	257 ,,

It was further desirable to ascertain the degree of dependence that might be placed on nailing two pieces together, and Mr. Bevan kindly undertook to make some trials. Two pieces of Christiana deal $\frac{7}{8}$ inch thick, were nailed together with two sixpenny nails; and a longitudinal force in the plane of the joint, and consequently at right angles to the direction of the nails, was applied to cause the joint to slide; it required a force of 712 lbs., and the time was 15 minutes; the nails curved a little and were then drawn.

Another experiment was made in the same manner with dry oak, an inch thick, in which the force required was 1,009 lbs.: the sixpenny nails curved, and were drawn by that force.

Dry sound ash, an inch thick, joined in the same manner by two sixpenny nails, bore 1,220 lbs. 30 minutes without sensibly yielding; but when the stress was increased to 1,420 lbs. the pieces separated with an easy and gradual slide; curving and drawing the nails as before, one of which broke.

327.—SCREWS. The adoption of screws instead of common nails is a considerable improvement; the following experiments on the force necessary to draw screws of iron, commonly called wood screws, out of given depths of wood, were made by Mr. Bevan. The screws he used were about 2 inches in length, ·22 inch diameter at the exterior of the threads, ·15 inch diameter at the bottom, the depth of the worm or thread being ·035 inch and the number of threads in 1 inch = 12. They were passed through pieces of wood,

exactly $\frac{1}{2}$ inch in thickness, and drawn out by the weights stated in the following table:—

Dry beech	460 lbs.
Ditto ditto	790 „
Dry sound ash	790 „
Dry oak	760 „
Dry mahogany	770 „
Dry elm	665 „
Dry sycamore...	830 „

The weights were supported about two minutes before the screws were extracted. He found the force required to draw similar screws out of deal and the softer woods about half the above.

The force necessary to cause pieces screwed together to slide at the joining, was also determined; the pieces being joined by two screws; the resultant of the force coinciding with the plane of the joint, and in line with the places of the screws.

With Christiana deal, $\frac{7}{8}$ inch thick, joined by two screws $1\frac{5}{8}$ inches in length, and $\frac{5}{40}$ inch in diameter within the worm, a load of 1,009 lbs. gradually applied broke both the screws at the line of joint, after elongating the interior of the hole and sliding about six-tenths.

With very dry seasoned oak, 1 inch thick, two screws $1\frac{5}{8}$ inches long, and $\frac{6}{40}$ inch diameter within the thread, bore 1,009 lbs. for ten minutes without any signs of yielding: with 1,137 lbs. both screws broke in two places; each screw about $\frac{2}{10}$ inch within each piece of wood; the holes were a little elongated.

With dry and sound ash 1 inch thick, with screws $2\frac{1}{4}$ inches long, passing $\frac{1}{4}$ inch through one of the pieces, the diameter at bottom of the worm $\frac{7}{40}$; a load of 1,224 lbs. was first applied, and gradually increased for two hours to 2,661 lbs.; this produced a slow and moderate sliding, not separation, the screws being neither drawn nor broken; but probably would, if not removed on account of night coming on, and putting an end to the experiment.

328.—Iron nails and other small fastenings might be rendered much more lasting by boiling them in linseed oil. This is often practised by slaters to protect their nails from rust.

As it is difficult to heat large articles, a coating that can be applied in a cold state is much better. One that dries quickly, and it is said perfectly preserves from rust the metals upon which it is laid, is described in the Repertory of Arts. It is prepared as follows: Grind to an impalpable powder one part (by weight) of black lead (plumbago), with which mix four parts of sulphate of lead, and one part of sulphate of zinc: to this mixture add, by degrees, sixteen parts of boiled linseed oil.

As strapping is often applied to prevent accidents, and to connect the parts where the timber itself is likely to decay, it is obvious that the iron-work should be rendered as durable as possible, and particularly where it is exposed to the weather.

The method now adopted for rendering nails or other iron fastenings durable, is to give them a coating of tin or zinc; when zinc is used the process is called "galvanising."

SECTION X.

ON THE NATURE AND PROPERTIES OF TIMBER.

329.—WOOD is that substance which forms the principal parts of the roots, trunks, and branches of trees and shrubs; and its usefulness, in buildings, ships, and the mechanical arts, is well known.

The *woods* of different trees differ much in strength, hardness, durability, and beauty; and, consequently, in their fitness for the various purposes to which they are applied. The wood which is felled and seasoned for the purpose of building is called *timber;* and in stating the properties of woods, we shall consider those only which are fit for timber.*

330.—If the stem or trunk of a tree be cut across, the wood is found to be made up of numerous concentric layers or rings, very distinct in some trees, but less so in others. One of these layers is commonly formed every year; consequently their number corresponds nearly with the age of the tree. Each layer consists, in general of two parts: the one solid, hard, heavy, and dark coloured; the other of a lighter colour, porous, and soft, which renders the lines of separation between the annual layers distinct. Scarcely any two layers of the same tree are precisely alike, either in the proportion of the hard part, or in the thickness of the layers; as the layers vary in thickness according to the degree of vegetation which took place in the years of their formation: and also in the same tree they vary in thickness, either according to the situation of the principal roots, or the aspect: the annual layers being always thicker on that side of the tree which has been most favourable to the growth of the roots, or that has had the advantage of a good aspect.

331.—The structure of wood, and the nature of the vessels through which the fluids move in the living plant, are now tolerably well understood; although, indeed, the study of vegetable anatomy is attended with considerable difficulties; but some important facts have been ascertained, which contribute materially towards a more perfect knowledge of the nature and properties of wood.

Wood appears to be composed of various vessels, which in the living tree convey the fluids necessary to its growth; between those vessels there are cells interposed. There is nothing of the character of solid fibres in wood, except the thin membraneous coats of the cells and vessels, which adhere so slightly together in recently formed wood, that it is easy to separate them. The vessels in the growing tree are intended to convey a watery fluid, called

* The English word *timber* is derived by Dr. Johnson from the Saxon *timbrian*, to build; hence the above definition. The legal definition of timber is restricted to particular species of wood, and custom varies in different counties as to the species ranked among the timber trees.

the sap, from the roots to the leaves; when it arrives at the leaves it undergoes certain changes, and returns through the bark; and the bark being expanded by this accession of moisture, rises from the wood, and leaves a cavity that becomes filled with the proper sap, which gradually hardens and forms a new layer of wood.

332.—Timber trees belong to the great division of plants called "Exogens," or outward growers, from the increase taking place on the outside of the tree as it grows. The term "Dicotyledon" is also applied to these plants from the seed being always divided into two equal parts, which is especially noticed in the almond, walnut, and other seeds. If we cut the trunk of a tree transversely we find in the centre a soft material called the *pith*, or *medulla*, enclosed in a sheath called the *medullary tube;* this never alters in figure or size during the whole life of the tree. The *pith*, or *inner medulla*, is a loose, transparent, light, and spongy substance. The *wood* is that part which immediately surrounds the medullary tube, the section of which consists of a number of concentric circles or *layers*, the inner layers being the oldest portion, and more solid and compact than the outer layers. The outermost layers are called the *Alburnum*, or *false-wood*, which is wood in a young state without the tenacity or hardness of the older wood, from which it differs very much in colour, and can generally be distinguished in timber from being lighter than the inner wood; this part is commonly called by carpenters the *sap-wood*. Outside of the alburnum is the *Liber*, or *inner bark*, which is essential to the growth of the tree, which soon dies if a circle of it is removed, a process commonly adopted to clear American forests, and called *girdling*.

The *outer bark* consists of *cortical layers* surrounding the liber, but sometimes it is hardly to be distinguished therefrom. Outside this again is a substance termed the *herbaceous envelope*, which covers the whole of the trunk and branches, and is called the *outer medulla;* this contains the proper juices of vegetables, and has an organisation and uses similar to those of the pith or inner medulla. This is the substance which forms the *cork* of the *Quercus suber*, in which it is developed to an extraordinary thickness. This envelope performs an important part in the growth of the tree, as in it the carbonic acid absorbed from the air is decomposed, the carbon remaining in the interior, while the oxygen is discharged through the pores. This process, however, can only take place under the direct rays of the sun. It is partly renewed every year, and at the return of summer it incites the sap to ascend towards the buds.

The *epidermis* is the outer skin or *cuticle* which covers the trunk and branches, and consists of a thin transparent layer of uniform tissue composed of cellules and having numerous pores. It is but slightly extensible, and is easily torn by the enlargement of the trunk, when it often flakes off, as in the plane-tree.

333.—SAP is the colourless watery fluid which the root absorbs in the earth and the leaves in the air, for the purpose of supplying the tree with nourishment. This fluid ascends through the woody layers, especially in those which are nearest the medullary tube, and its progress is not arrested by depriving the tree of its bark, but if all the woody layers are removed it ceases to ascend, unless a small cylinder of woody layers is allowed to remain. In its passage upwards the sap communicates with the lateral parts and branches, giving off its water as it ascends, and depositing in the vegetable tissue the matter with which it is impregnated and destined for the nutrition of the tree and the reparation of its expended fluids.

The *descending sap* is very different to the ascending sap, being divested of the greater

part of its water, and also containing more nutritious principles by which it contributes essentially to the nourishment of the tree. The sap descends through a series of tubes in the liber or bark, where it is deposited to form new wood or alburnum, the older alburnum or innermost layers being converted into wood proper. Each year the innermost layer of alburnum becomes the outer layer of wood, and at the same time a new layer of alburnum is produced on the outside. (See Rhind's *History of the Vegetable Kingdom.*)

334.—*Medullary rays* are transverse communications which exist between the inner medulla or pith and the external tissue. Similar rays also appear in the thickness of the bark, and serve to connect the inner with the outer medulla. The medullary rays are much more conspicuous in some trees than in others, being strongly developed in the oak, which derives much of the beauty of its grain from the presence of these rays, sometimes termed the *silver grain.*

335.—The *alburnum*, or that part of the wood next the bark, is commonly called *sap-wood*, and from the character of its structure it is more prone to decay than the internal part of the tree, called the *heart-wood.**

The sap-wood is softer, and generally lighter coloured, than the heart wood, and contains a considerable portion of vegetable matter, which partakes of the nature of the descending sap. It is found to decay rapidly, and is also very subject to worms. The reason is obvious, for it contains the food which they live upon, the most of which is absorbed or evaporated from the heart-wood. In many kinds of wood, especially those of a dark colour, there is a strong line of demarcation between the sap-wood and the heart-wood.

The proportion of sap-wood in different trees varies very much: Spanish chesnut has a very small proportion of sap-wood, oak has more, and fir a still larger proportion than oak; but the proportions vary according to the situation and soil. Three specimens of a medium quality gave the following:—

Chesnut, whole age	58	years,	15½	inches	diameter,	7	years	sap-wood,	⅜	inch thick.
Oak, whole age	65	„	17	„	„	17	„	„	1¼	„
Scotch fir ...	...	...	24	„	„	„	„	„	2½	„

Therefore, if the diameter be unity, or 1, that part of it which is sap-wood will be, in the chesnut, 0·1; in the oak, 0·294; and in the Scotch fir, 0·416. The Scotch fir was the produce of the Mar Forest.†

336.—The life of trees, like that of men, has been commonly divided into three stages; infancy, maturity, and old age. In the first, the tree increases from day to day; in the second, it maintains itself without sensible gain or loss; but, in the third, it declines. These stages vary in every species according to the soil, the aspect, the climate, or the nature of the individual plant.

Sir H. Davey states,‡ that oak and chesnut trees decay sooner in a moist soil than in a dry and sandy one, and their timber is less firm. The sap-vessels being expanded with

* The properties of the different kinds of sap that have been examined are given in works on Chemistry.

† These measures were taken from specimens in the collection of W. Atkinson, Esq., late Architect to the Ordnance, &c.

‡ *Agricultural Chemistry.*

moisture without the necessary quantity of nourishing matter, the general texture becomes necessarily less firm. Such wood splits easily, and is very liable to shrink and swell with the changes of the weather.

Trees of the same kind arrive at the greatest age in that climate which is best adapted to their nature. The common oak, the fir, and the birch thrive best towards the northern, the ash and the olive tree thrive best towards the southern, parts of Europe.

We find, says Mirbel, the ashes of Calabria and Sicily to be longer-lived than those of Prussia or Great Britain.* Oak and chesnut trees, under favourable circumstances, sometimes attain an age of about 1,000 years; beech, ash, and sycamore seldom arrive at half that age.

The decline of trees appears to be caused by the decay of the heart-wood. It is this, as Sir H. Davy remarks, which seems to constitute the great limit to the age and size of trees: and the long period the central parts are preserved by the cooling influence of the living trees is truly wonderful.

In trees that have not arrived at maturity, the hardness and solidity of the wood are greatest at the heart, and decrease towards the sap-wood; but in the mature or perfect tree the heart-wood is nearly uniform; while that of a tree on the decline is softer at the centre than it is next the sap-wood. These observations were made by Buffon in the course of his numerous experiments, and also by Duhamel.

ON FELLING TIMBER.

337.—"It should be," says the venerable Evelyn, "in the vigour and perfection of trees that a felling should be celebrated."† When a tree is felled too soon, the greater part of it is sap-wood, and in a young tree even the heart-wood has not acquired its proper degree of hardness; indeed the whole tree must partake so much of the nature of sap-wood, that it cannot be expected to be durable. And when a tree is not felled till it be on the decline, the wood is brittle and devoid of elasticity, tainted, discoloured, and soon decays. But in trees that have arrived at a mature age, the proportion of sap-wood is small, and the heart-wood is nearly uniform, and is hard, compact, and durable. Hence it is important that Evelyn's precept should be carefully attended to. It is true the proper age for each species has not been satisfactorily determined; but it is a point where great accuracy is not necessary; for half-a-dozen years in the age of a tree will not make much difference, provided it be not cut too soon. It is cutting trees before they have arrived at maturity that should be guarded against; and as it is most likely to happen from interested motives, it is the more necessary to caution the carpenter in this respect. Trees increase slowly in size after they arrive at a certain age; therefore it is the interest of the timber grower to fell them before they arrive at maturity; because it is his object to obtain the greatest possible quantity of timber, without regard to the quality. But when the carpenter is sensible of the inferior quality of young timber in respect to duration, it is his province to check this growing evil, by giving a better price for timber that has acquired its proper degree of density and hardness.

* *Journal of Science, &c.*, vol. iv.

† *Silva, or a Discourse on Forest Trees.*

The period generally allowed for an oak tree to arrive at maturity is 100 years, and the average quantity of timber produced by a tree of that age is about $1\frac{1}{2}$ loads, or 75 cubic feet. In some instances oak trees arrive at maturity in a less time than 100 years, and in others not until after that period.*

The age of an oak tree, according to Daviller, should never exceed 200 years, nor should it be felled at a less age than 60.† Belidor states about 100 to be the best age for the oak.‡ It is much to be regretted, that in districts where the oak flourishes it is seldom suffered to attain a mature age; being often cut before the trees will produce 50 feet of timber each.

The ash, larch, and elm should be cut when the trees are between 50 and 100 years old; and between 30 and 50 is a proper age for poplars.

The Norway spruce and Scotch pine are generally cut when between 70 and 100 years old in Norway.

338.—In order that timber may be durable, it is also necessary to attend to the proper season of the year for felling. But on this point there is much difference in opinion, and the question is only to be decided by attending to the state of trees at different seasons of the year. The best period for felling timber is undoubtedly that in which it is most free from extraneous vegetable matter; or such matter as is intended to be expended in forming leaves and buds, which is in a more fluid state, and of a more saccharine and fermentible nature than the proper juices, or such as form the wood. A tree deposits in the woody layers a portion of matter to be dissolved by the rising sap, and at the period when the leaves are putting forth, the wood must be filled with matter in a state ready for germination; consequently the timber cut at that period must be easily acted upon by heat and moisture, and subject to rapid decay, or to be destroyed by worms. In the spring trees are in a state of vegetation; therefore at this time it is desirable to avoid felling timber for any other than temporary purposes, because the trees then contain the greatest quantity of matter in a state fit for germination.

On the other hand, the best time for felling timber is in late autumn or winter, as at these times the vegetative powers are at rest. In some kinds of trees, however, a little after midsummer appears to be decidedly the best time for felling. Alder felled at that time is found to be much more durable; and Ellis says that beech, when cut in the middle of summer, is better and less liable to be worm-eaten; particularly if a gash be cut to let out the sap some time before felling.§ Mr. Knowles states that "about Naples, and in other parts of Italy, oaks have been felled in summer, and are said to have been very durable."‖

339.—But in oak trees the bark is too valuable to be lost; and as the best period for the timber is the worst for the bark, an ingenious method has been long partially practised, which not only secures the bark at the best season, but also materially improves the timber. This method consists in "girdling" or taking the bark off the standing tree early in the spring, and not felling it until after the new foliage has put forth and died. For by the production of new buds the fermentible matter is expended, and the sap-wood becomes

* *First Report of the Commissioners of Woods and Forests*, 1812.
† *Cours d'Architecture.*
‡ *Sciences des Ingénieurs.*
§ Ellis's *Timber Tree Improved.*
‖ *Inquiry into the means which have been taken to preserve the British Navy*, 1821.

nearly as hard and durable as the heart-wood, being both less liable to decay and to be destroyed by worms.

Buffon has ascertained by experiment that the wood is materially improved by this method of barking the trees standing in the spring, and felling them about the end of October.* Duhamel, whose extensive knowledge of the nature and qualities of woods is well known, recommends the same method; and Evelyn states, that "to make excellent boards and planks, it is the advice of some, you should bark your trees in a fit season, and so let them stand naked a full year before the felling." But a tree will not be benefited by standing so long; and the best time for felling appears to be when the new foliage has put forth and died, as Mr. S. Pepys observes in his paper on the subject.† And Mr. T. A. Knight, to whom we are indebted for many interesting as well as important facts respecting timber, has made some experiments and observations, from which he concludes, that in all cases where it is essential to give durability to the sap-wood of oak, the trees should be barked in the spring, and felled in the ensuing winter;‡ also that winter-felled heart-wood is less affected by moisture, and likely to be the best and most durable. In Burmah the Teak tree is girdled three years before being felled.

When the bark of a tree is not of sufficient value to defray the expense of stripping, the timber should be felled during the months of December, January, or February in the winter, or during the month of July in the summer. Winter felling is recommended by most writers; but Mr. Knowles is of opinion that it is better chiefly in consequence of the timber being less liable to split or twist in seasoning, from the drying being more gradual when it is cut at that time of the year.§ The advantage of slow drying may, however, be easily given at any season; and it certainly is a great advantage in this early stage of seasoning. According to Vitruvius, the proper time for felling is between October and February; and he directs that the trees should be cut to the pith, and then suffered to remain till the sap be drained out. The effusion of the sap prevents the decay of timber; and when it is all drained out, and the wood becomes dry, the trees are to be cut down, when the wood will be excellent for use.

A similar effect might be produced by placing the timber on its end as soon as it is felled, and it would no doubt compensate for the extra expense by its durability in use.

In France, so long ago as 1669, a royal ordinance limited the felling of naval timber from the 1st of October to the 15th of April. Buonaparte directed that the time for felling naval timber should be from the 1st of November to the 15th of March, in order to render it more durable.

ON SEASONING TIMBER.

340.—When timber is felled, the sooner it is removed from the forest the better; it should be removed to a dry situation, and placed so that the air may circulate freely r[illegible]

* *Moyen facile d'augmenter la Solidité, la Force, et la Durée du Bois; Mémoires de l'Academie de* [illegible] Paris, 1738.

† *Philosophical Transactions*, vol. xvii.

‡ *Annals of Philosophy*, vol. xiv; or *Philosophical Transactions*, 1820.

§ *Inquiry into the means which have been taken to preserve the British Navy*, 1821.

each piece, but it should not be exposed to the sun and wind. Squared timber does not rift or split so much as that which is round; and where the size of the trees will allow of it, it is better to quarter them, after a period of very slow drying in the whole tree. When beams are to be used the full size of the tree, it would be a good preservative against splitting to bore them through from end to end, as is done in a water-pipe. It is irregular drying which causes timber to split; and this method would assist in drying the internal part of the beam, without losing much of its strength; at the same time it would lighten it considerably.*

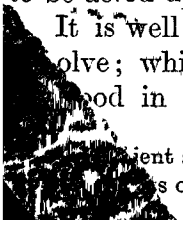
Duhamel has shown that it is a great advantage to set the timber upright, with the lower end raised a little from the ground;† but as this cannot always be done, the timber-yards should be well drained, and kept as dry as possible. Paved yards are to be preferred, and the paving should have a considerable fall, to prevent water standing. If the paving were laid with ashes it would be better; those from a forge or foundry would be excellent: even an unpaved yard would be improved by a coat of ashes, to prevent anything growing among the timber.

If timber can be kept some time in a dry situation before it is cut into scantlings, it is less subject to warp and twist in drying; but during the time it is kept in the tree or log it should be carefully piled, so as to leave space for a free circulation of air between each piece, and also between the timbers and paving or ground. In some of the Government yards, the timber has been laid upon cast-iron bearers, instead of being laid upon refuse pieces of wood; as the refuse wood is often half rotten, and must in some degree contribute to infect the sound timber. Timber is too often suffered to lie half buried in the ground, or grown over with weeds, till it is covered with fungus, and impregnated with the seeds of decay before it is brought to use.

When it is necessary to convert the timber into smaller scantlings, it still requires attention; as the better it is seasoned, when brought into work, the better the work will stand: it will also be more durable. The experiments of Duhamel show that such scantlings will dry soonest in an upright position, and that the upper end dries more rapidly than the lower one. But whether the pieces of timber be piled on the end, or laid horizontally, a free space should be left round each piece, and the situation should be dry and airy; yet not exposed to the direct rays of the sun, nor to a strong current of air. If the scantlings be laid horizontally, short blocks should be put between them; which will preserve them from becoming mouldy, and will contribute much towards rendering the sappy parts more durable.

Gradual drying, where the time can be allowed for it in the natural process, is the most certain means of giving durability to timber, by fixing those parts of it which are most liable to be acted upon by heat and moisture.

It is well known to chemists that slow drying will render many bodies less easy to olve; while rapid drying, on the contrary, renders the same bodies more soluble: besides, od in drying loses a portion of its carbon, and the more in proportion as the



ient architects," says Alberti, "not only prevented the access of the scorching rays of the sun, and s of winds, but also covered the surface with cow-dung, to prevent the too sudden evaporation from

temperature is higher. There is in wood that has been properly seasoned a toughness and elasticity which is not to be found in rapidly dried wood. This is an evident proof that firm cohesion does not take place when the moisture is dissipated at a high heat. Also, seasoning by heat alone produces a hard crust on the surface, which will scarcely permit the moisture to evaporate from the internal part, and is very injurious to the wood.

For the general purposes of carpentry, timber should not be used in less than two years after it is felled; and this is the least time that ought to be allowed for seasoning. For joiners' work it requires four years, unless other methods be used; but for carpentry natural seasoning should have the preference, unless the pressure of the air be removed.

Duhamel says, that the quantity of matter which ought to be evaporated from green oak is about one-third or two-fifths of its weight: the proportion, however, will vary according to the age and quality of the timber, and the nature of the soil that produced it. In a subsequent article we have attempted to establish the relation between the size of the pieces and the time necessary to season them (see Article 348); as it is a subject that has not received that share of attention which its importance merits.

341.—The following table gives the results of Mr. Laslett's experience on the times required for seasoning pieces of oak and fir of various scantlings placed under cover and protected from wind and weather:—

Pieces 24 inches square and upwards,									Oak required	26	months,	Fir	13	months.	
„	under 24 inches to 20 inches square,								„	„	22	„	„	11	„
„	„	20	„	„	16	„	„		„	„	18	„	„	9	„
„	„	16	„	„	12	„	„		„	„	14	„	„	7	„
„	„	12	„	„	18	„	„		„	„	10	„	„	5	„
„	„	8	„	„	4	„	„		„	„	6	„	„	3	„

Planks required from one-half to two-thirds the above time, according to thickness. He found that if the pieces are kept longer than the periods named, the thin fine *shakes* which first open upon the surface during the process of seasoning will open deeper and wider until they may render the logs unfit for conversion. If, however, the logs are reduced to the required scantlings after partial seasoning, and then allowed to dry, they will not be liable to tear open so much; but by shrinking gradually will retain a more solid form.*

ON WATER SEASONING.

342.—On account of the time required to season timber in the natural way, various methods have been tried to effect the same purpose in a shorter time. Perhaps the best of these is to immerse the timber in water as soon as it is cut down; and after it has remained about a fortnight in water, but not more, to take it out, and dry it in an airy situation.

Evelyn directs to "lay your boards a fortnight in water (if running the better, as at a mill-pond head), and then setting them upright in the sun and wind, so as it may pass freely

* *Timber and Timber Trees*, by T. Laslett.

through them, turning them daily; and thus treated, even newly-sawn boards will floor far better than those of a many years' dry seasoning, as they call it." And he adds: "I the oftener insist on this water seasoning, not only as a remedy against the worm, but for its efficacy against warping and distortions of timber, whether used within or exposed to the air."

Duhamel, who made many experiments on this important subject, states that timber for the joiner's use is best put in water for some time, and afterwards dried; as it renders the timber less liable to warp and crack in drying; but he adds, "where strength is required it ought not to be put in water." And he found, from numerous experiments, the timber which had remained some time in fresh water lost more of its weight in drying than that which was dried under cover; and he observed, that green timber that had been steeped in water for some time was always covered with a gelatinous substance.

Timber that has been cut when the tree was full of sap, and particularly when that sap is of a saccharine nature, must be materially benefited by steeping in water; because it will undoubtedly remove the greater part of the fermentible matter. Duhamel has ascertained that the sap-wood of oak is materially improved by it, being much less subject to worm-eat; and also that the tender woods, such as alder and the like, are less subject to the worm when water-seasoned. Beech is said to be much benefited by immersion; and green elm, says Evelyn, if plunged four or five days in water (especially salt water), obtains an admirable seasoning.

When timber is put in water it must be sunk so as to be completely under water, as nothing is more destructive than partial immersion. Salt water is considered best for ship-timber; but for timber to be employed in the construction of dwelling-houses fresh water is better.

ON STEAMING AND BOILING TIMBER.

343.—Though steaming or boiling impairs the strength and elasticity of timber, it gives another property, which for some purposes is still more desirable than strength; for boiled or steamed timber shrinks less and stands better than that which is naturally seasoned. Therefore it may often be useful to season timber in this manner where joiner's work is to be executed in oak of British growth, as without this precaution it requires a long time to season it so as to be fit for such purposes.

The timber should not remain long in boiling water or steam; four hours will in general be quite sufficient; and after boiling or steaming the drying goes on very rapidly, but it is well not to hasten the drying too much. Steamed wood dries sooner than that which is boiled, according to Mr. Hookey's experiments.*

How far steaming or boiling affects the durability of timber has not been satisfactorily ascertained; but it is said that the planks of a ship, near the bows, which are bent by steaming, have never been observed to be affected with the dry rot. The changes produced by boiling, as observed by Duhamel, are not very favourable to the opinion that it adds to the durability of timber. For when a piece of dry wood was immersed in boiling water,

* Barlow's *Essay on the Strength of Materials.*

and afterwards dried in a stove, it not only lost the water it had imbibed, but also a part of its substance; and when the experiment was repeated with the same piece of wood, it lost more of its substance the second time than it did the first. The same thing takes place in green wood; and tender woods, or those of a middling quality, are more altered by these operations than hard woods, or those of a good quality. Dr. Watson found steeping long in cold water produced similar effects; but that box, oak, and ash lost more weight by this process than mahogany, walnut, or deal.* Both cold and hot water have therefore to a certain extent the power of dissolving the woody fibre.

ON SMOKE-DRYING, SCORCHING, AND CHARRING TIMBER.

344.—It is an old and a well-founded observation, that smoke-drying contributes much to the hardness and durability of wood. Virgil seems to have been aware of its utility when he wrote the passage which is thus translated by Dryden:

> "Of beech the plough-tail, and the bending yoke,
> Or softer linden *harden'd in the smoke*."† GEORGICS, i, 225.

But this method can only be effectually applied on a very small scale; yet sometimes, for particular purposes, it may be useful to season in the smoke. As a substitute for the smoke of an open chimney, Ellis advises to burn fern, furze, straw, or shavings under the timber,‡ which would destroy any seeds of fungi, or worms, and so embitter the external surface as to prevent any further ill effect from either. It would be easy to contrive the means of smoke-drying for the use of a manufactory where much seasoned wood was used.

Scorching must do timber much harm when it is done hastily, so as to cause rents and cracks in it; as these become receptacles for moisture, and consequently must be the cause of rapid decay.

It must be always remembered, that charring the surface is only useful in as far as it destroys and prevents infection; and that it should be applied only to timber already seasoned: for when it is applied to green timber, it only closes up the pores at the surface, so that the internal sap and moisture cannot evaporate.

In that kind of decay which arises from the constant evaporation of moisture, charring the surface produces no effect. Duhamel made some experiments on this point, and found that there was very little difference between the posts he had charred, and those he had not charred, at the end of six years; but as a preventive of infection by the dry rot, and of the worm in timber, charring appears to be very beneficial, and will no doubt be assisted by impregnating the timber with the bitter particles of smoke.

* *Chemical Essays.*

† Beckman, in his *History of Inventions*, quotes a passage from Hesiod to the same effect; and adds, "as the houses of the ancients were so smoky, it may be easily comprehended how, by means of smoke, they could dry and harden pieces of timber." In this manner were prepared the pieces of wood destined for ploughs, waggons, and the rudders of vessels:

> "These long suspend, where *smoke* their strength explores,
> And seasons into use, and binds their pores." SOTHEBY'S VIRGIL.

‡ *Timber Tree Improved*, by Mr. Ellis.

LANGTON'S METHOD OF SEASONING TIMBER BY THE DIRECT EXTRACTION OF THE SAP.

345.—As green wood consists of woody fibre saturated with the fluid called the natural sap of the tree, it is obvious that a method of separating this sap without injury to the woody fibre is one of the most important discoveries that has been made in the management of timber. For everything which shortens the time between the felling a tree and its being fit for use without injuring it in strength and durability, is a means of lessening the quantity of capital required to keep a stock of dry wood, and of preventing green wood being used in cases where the stock of dry is deficient. From three to five years is, in the usual method, necessary to render green wood fit for use; and for so long not only is the interest of the capital employed to purchase it lost to the consumer, but also the manufacturer must have a greater capital to conduct his business than with a quicker mode of drying. In ship-building the disadvantages of the slow process of seasoning by the natural action of the atmosphere are most evident.

When green wood is placed in the receiver of an air pump, as the air is exhausted by the pump, the sap, being no longer confined by the atmospheric pressure, separates from the wood; and if heat be applied so as to convert this sap into vapour as fast as it arrives at the surface of the wood, and the means of condensing the vapour be provided, the whole of the sap will soon be extracted from the wood. This is the nature of Mr. Langton's process; but in practice he employs vertical cylinders of iron to contain the wood, into which the pieces are lowered by a crane, and raised again when the operation is done; steam is used to produce a partial vacuum in the cylinders after the wood is in and the covers closed, and heat is applied by means of a water-bath surrounding the cylinders, rendering it easy to obtain a regular temperature. The vapour of the sap is conveyed by a pipe to pipes or vessels surrounded by cold water, where it condenses and is collected in the liquid state; it is nearly clear, has a sweetish taste, and very peculiar flavour, with a musty disagreeable smell when it has been kept some time; it has a small quantity of free acid in it, and a light flocculent matter floats in it, which appears to afford the musty smell.

The wood seasoned in this manner rather exceeds the usual density of the same kind equally dry, and loses about the same weight as in seasoning by the common process, with somewhat more shrinkage. The time when the process is over is easily known by the liquid ceasing to collect in the condensing part of the apparatus, and the trial may be made with still greater accuracy by a barometer gauge (such as is used for steam-engine condensers); for, on closing the communication between the cylinder and the condenser, the vapour in the cylinder will increase in force, which, being indicated by the gauge, shows that the operation is not complete.

In regard to expense, it appears that to season, or rather to extract the whole of the sap from green wood, will require from eight to twelve weeks (Art. 349), and cost about 10 shillings per load. We believe this mode of seasoning is now almost wholly discontinued.*

* The patent was obtained in 1825, and is inserted at length in the *Repertory of Patent Inventions*, vol. vi.

TABLES OF THE WEIGHT OF TIMBER IN DIFFERENT STATES.

346.—As a suitable introduction to some remarks on seasoning, we subjoin the following tables.

Weight of a cubic foot of Timber, green, and also its weight a year afterwards.

[From Duhamel's experiments; reduced to English weights and measures.]

Kind of Wood.	Weight of a cubic foot green.	Weight of a cubic foot one year afterwards.	Loss by seasoning per cubic foot.	
	lbs.	lbs.	lbs.	per cent.
Oak of Provence	78·25	68·3	10 or	12·8
Elm „	57·14	47·5	9·6 „	17
Poplar „	49·68	30·69	19 „	38
Walnut „	54·43	44·08	10·3 „	19
Lime „	45·2	27·96	17·2 „	37·8
Beech of Burgogne ...	56·25	43·95	12·2 „	21·8
White pine of Provence ...	53·73	43·93	9·8 „	18·5
Norway pine, dry ...	...	36·75	...	

The writer of an article on timber in the *Encyclopédie Méthodique*, states that the weight of a cubic foot of green oak varies from 62·5 to 66 lbs.; of a cubic foot of seasoned oak, from 53·5 to 58 lbs.; and a cubic foot of very dry oak, from 44·6 to 47·3 lbs. The timber of very old trees is often much lighter than this; the author tried specimens from old trees that did not exceed 38·5 lbs. per cubic foot when dry. When the specific gravity is very low it may be safely concluded that it is the wood of an old tree, and that it will be brittle and deficient both in strength and toughness.

Some experiments have been made on the loss of weight in seasoning by Mr. Couch, at the Royal Dockyard at Plymouth, from which the following are taken:—*

* Mr. Couch's "Table" is published in Barlow's *Essay on the Strength of Materials*, and contains much valuable information. Mr. Knowles, in his *Inquiry*, &c., has added the following on two cubes of oak:—

Weight when felled, 62 lbs. Weight when perfectly dry, 36½ lbs. Loss of weight, 41·5 per cent.
„ „ 68 „ „ „ 11·06 „ „ 40 „

Weight of Wood in different States; from Mr. Couch's Experiments.

Kind of Wood.	Weight when felled of a cubic foot.	Weight seasoned of a cubic foot.	Shrinkage in seasoning.
	lbs.	lbs.	
Oak (butt-end)	69	$47\frac{1}{2}$	$\frac{1}{32}$
Elm	$58\frac{1}{2}$	$36\frac{1}{2}$	$\frac{1}{44}$
	Weight of a cubic foot when first imported.		
Riga masts	42	40	$\frac{1}{72}$
Pitch pine, American ...	47	$46\frac{1}{4}$	$\frac{1}{40}$
Yellow pine „ ...	$42\frac{1}{2}$	$28\frac{3}{4}$	$\frac{1}{144}$
Spruce pine „ ...	33	$32\frac{3}{4}$	$\frac{1}{112}$

To these experiments the following new ones are added, which include some varieties of wood not before tried :—

Kind of Wood.	Weight of a cubic foot when green.	Weight of a cubic foot dry.	Loss per cent.
	lbs.	lbs.	
Oak sap-wood (*Quercus sessiliflora*) ...	67·0	47·07	29·8
Spanish chesnut	54·68	37·91	30·6
Larch	42·06	30·99	26·0
Walnut	57·5	38·5	33·0
Acacia (*Robina pseudo-acacia*)	51·25	46·76	9·0

We are also indebted to Mr. Wiebeking for some experiments on seasoning timber; and as both the kinds of timber and the times of observation are different from those already noticed, his table is a considerable addition to our knowledge of this important subject. It is, in common with all the other tables in this work, reduced to English weights and measures.

*Weight of a cubic foot of Wood in different States.**

Kind of Wood.	Weight of a cubic foot fifteen days after the wood was felled.	Weight of a cubic foot after three months' exposure to the air.	Weight of a cubic foot when dry.
	lbs.	lbs.	lbs.
Oak	58·74	56·18	39·27 to 39·58
Larch	53·63	51·08	38·31
Pine (*Pinus sylvestris*)	51·08	38·31	26·817
Pinaster	52·35	33·2	25·54
Fir (*Pinus picea*)...	33·2	29·37	25·22 to 25·54

* *Traité contenant une Partie Essentielle de la Science de construire les Ponts.*

The following table gives the loss of weight in various woods after ten years' seasoning, from Mr. Fincham's experiments :—*

Kind of Wood.	Weight of a cubic foot.		Loss by seasoning, per cubic foot average.	
	Green average.	Seasoned average.		
	lbs.	lbs.	lbs.	per cent.
Oak, English	61	50	11 or	18
„ Istrian	68	53	15 „	22
„ Styrian	55	43	12 „	21·8
„ Dantzic	54	44	10 „	18·5
„ African	65	59	6 „	9·2
Larch, Italian	40	37	3 „	7·5
„ Polish	41	37	4 „	9·8
„ Scotch	34	30	4 „	11·8
Elm, English	59	37	22 „	37·3
„ Canada	57	48	9 „	15·8
Cedar, Cuba	31	27	4 „	13
„ New South Wales...	32	28	4 „	12·5
Pitch Pine	42	41	1 „	2·4

Transverse shrinkage of a Board 12 *inches square,* $\frac{1}{2}$ *inch thick, after thirteen years' seasoning, from Mr. Fincham's Experiments.**

Kind of Wood.	Butt.	Top.
Oak, English	$\frac{1}{12}$ the breadth	$\frac{1}{13}$ the breadth
„ African	$\frac{1}{27}$ „	$\frac{1}{32}$ „
Fir, Riga	$\frac{1}{32}$ „	$\frac{1}{32}$ „
„ Dantzic	$\frac{1}{38}$ „	$\frac{1}{38}$ „
Pine, Virginia	$\frac{1}{27}$ „	$\frac{1}{38}$ „
„ Yellow	$\frac{1}{38}$ „	$\frac{1}{48}$ „
Larch	$\frac{1}{27}$ „	$\frac{1}{48}$ „
Elm, English	$\frac{1}{24}$ „	$\frac{1}{27}$ „
„ Canada	$\frac{1}{16}$ „	$\frac{1}{21}$ „

Wood, when it is cut into small pieces, very soon acquires its utmost degree of dryness. Dr. Watson, Bishop of Llandaff, in the month of March, cut a piece from the middle of a large ash tree that had been felled about six weeks, and weighed it; its weight was 317 grains; in seven days it lost 62 grains, or nearly one-fifth of its weight. It was weighed again in August of the same year, but had not lost any more of its weight; hence it had become perfectly dry in the short space of seven days. He also found that the sap-wood of oak lost more weight in drying then the heart-wood, in the proportion of 10 to 7.†

Mr. Pontey has ascertained that the sap-wood of larch loses two-fifths of its weight in drying.‡

* *Treatise on Ship-Building.* † *Chemical Essays.* ‡ *Forest Pruner.*

LAWS OF SEASONING.

347.—The time that is required to season, or to dry a piece of timber, obviously depends upon its magnitude: for we have seen that in a small piece it will become perfectly dry in a few days: therefore some rule in this respect is desirable. A complete solution of the problem cannot be effected without more accurate experiments had been made on pieces under various circumstances. But until something better shall be done, the following investigation may be useful:—

The time required to dry a piece of timber, all other things being the same, will depend on the quantity of surface exposed to the action of the air; therefore, while the quantity of timber remains the same, the larger the surface the sooner it will be dry.

Also, if the quantity of surface remain the same, the time of drying will be proportional to the quantity of matter; as the greater the quantity of matter under the same surface the longer it will be in drying.

Let l be the length of a tree, which may be supposed to be a cylinder, and d its diameter, and $\pi = 3{\cdot}1416$.

Then, by the principles of mensuration, the surface of the cylinder is equal to $\pi d l + \frac{1}{2}\pi d^2$; and its solid content is $\frac{1}{4}\pi d^2 l$. But the time of drying will vary in the inverse ratio of the surface, and directly as the solid content; call this time T. Then $\frac{\frac{1}{4}\pi d^2 l}{\pi d l + \frac{1}{2}\pi d^2}$ varies as T, or $\frac{dl}{l + \frac{1}{2}d}$ varies as T. And, if c be a constant quantity, to be found from experiments, we have $\frac{cdl}{l + \frac{1}{2}d} = \mathrm{T}$, when the beam is cylindrical.

And in a rectangular beam $\frac{cbdl}{lb + ld + bd} = \mathrm{T}$; where b is the breadth and d the depth of the beam. When a table of reciprocals is at hand, the latter rule becomes much more convenient for calculation under the form $\frac{c}{\frac{1}{d} + \frac{1}{b} + \frac{1}{l}} = \mathrm{T}$.

This investigation is made on the supposition that the evaporation is free and equal at every part of the surface; but this is not the case in seasoning, as the evaporation from the ends is greater than from the sides, and greater from the upper side than from the under one. If e be the quantity evaporated by the end, when the quantity from the side is s, then for a cylinder

$$\frac{cdl}{ls + \frac{1}{2}de} = \mathrm{T}.$$

Equal drying would be much promoted by often turning the pieces, and by keeping them free from the ground or other damp bodies; and the more equal the drying is, the more nearly these rules will apply.

Timber is used in two states, that is, when it is *dry*, and when it is only *seasoned*. The term seasoned, however, is not very accurately defined. Rondelet considers timber to be sufficiently seasoned for carpenter's work (unframed he must intend) when it has lost about

one-sixth of its weight. But according to the author's own observations, timber has undergone what is termed a proper seasoning for common uses when it has lost about one-fifth of its weight; therefore, we shall call that timber *seasoned* which has lost one-fifth of the weight it had at the time of felling.

It also appears, from the experiments of Duhamel and Couch, that timber loses about one-third of its weight in becoming dry; and such a degree of dryness being sufficient for the joiner's purpose, we may consider timber *dry* when it has lost one-third of its weight.

Thus the terms *dry* and *seasoned* will have a more certain meaning: and when drying is carried to its greatest degree, the timber may be called *perfectly dry*, to distinguish it from that degree of dryness which renders it fit for framing and joiners' work.

348.—In order to compare the times required to season and to dry timber, when the sizes of the pieces remain the same, it will be necessary to consider the progress of evaporation from the same quantity of surface.

Let the whole time be conceived to be divided into equal parts; then if the quantity evaporated during any one of these parts of the time be n W, the whole quantity of sap being W: then as the time increases, the quantity of moisture decreases; and the force of evaporation being proportional to the excess of moisture, the quantity evaporated must decrease as the time increases, and the time is expressed by the equation, $\mathrm{W}\left(1-\frac{1}{n}\right)^t = w$, where w is the quantity of moisture the wood retains.

But for calculation we must employ logarithms; and then if $\frac{\mathrm{W}}{w} = m$, the equation becomes $\frac{\text{log. } m}{\text{log. } n - \text{log. } (n-1)} = t$ the time.

When timber is dry $m = 12$; and in seasoning in the open air $n = 20$ nearly; the timber losing one-third of its weight; but in seasoned timber $m = 2{\cdot}5$, and $n = 15$; the time being expressed in months.

Hence it appears how slowly the process of drying goes on; and the preceding equations showing that it proceeds most rapidly in small pieces, the importance of reducing timber to its proper scantlings for use is obvious. For, however dry a piece of timber may be, when it is cut to a smaller scantling it will shrink and lose weight, being always less dry in the centre than at the surface; and the more rapidly the drying has been carried on, the greater will be the difference. Nevertheless, in the first stages of seasoning it is best that it should proceed slowly; otherwise the external pores shrink so close as not to permit the free evaporation of the internal moisture, and the piece would split from unequal shrinking; and lastly, it should be reduced nearly to the proper scantling some time before it be framed.

The long time which large pieces require to season should render their use less frequent, without a proper time can be allowed. In the following table is given the times of drying and seasoning pieces of different sizes, calculated by the rules laid down in this article, which may be useful, as it shows at once the time necessary to bring different scantlings to the same degree of dryness. The time of seasoning, however, varies greatly in different kinds of wood, oak requiring twice as long as fir. (See Article 341.)

Table of the Times of Seasoning, &c., in the Open Air.

Length in feet.	Breadth in inches.	Thickness in inches.	Time of seasoning in months.	Time of drying in months.
10	6	6	11	29
10	8	8	15	39
12	10	10	18	48
12	12	12	22	57
12	14	14	25	66
12	16	16	29	76
18	18	18	32	86
20	20	20	36	96

The time under cover is shorter in the proportion of 5 to 7.

349.—If we place a body containing a fluid in a space from which the air is exhausted, the evaporation in a given time will be nearly directly as the difference between the force of vapour corresponding to the temperature of the evaporating surface, and the actual force of the vapour occupying the space, and which is regulated by the action of the condenser; or as $f - f'$.

Also, the motion of a fluid from the centre to the surface of the body will be as the square root of the mean difference between the pressure of the atmosphere and the force of vapour in the space, or as $\sqrt{\frac{1}{2}(p-f')}$; hence, if a be the quantity evaporated in a given time when $p = 30$ inches; $f = \cdot 516$ the force corresponding to 60°, and $f' = \cdot 25$ inches, the force corresponding to the average dew point; then

$$(\cdot 516 - \cdot 25) : (f - f')\sqrt{\tfrac{1}{2}(p-f')} :: a : \frac{a(f-f')\sqrt{\frac{1}{2}(p-f')}}{0 \cdot 266}.$$

It further appears that the temperature, or rather the force f, must be regulated so that the evaporation does not exceed the velocity of the fluid; therefore, $\sqrt{0 \cdot 266} : \sqrt{\frac{1}{2}(p-f')} :: 0 \cdot 266 : \sqrt{\cdot 133(p-f')} = f - f'$, or $f' + \sqrt{\cdot 133(p-f')} = f$, the force corresponding to the temperature in inches of mercury. And since $p = 30$ inches, and $f' = 3$ inches in the usual mode of condensation, we have $f' + \sqrt{\cdot 133(30-3)} = 4 \cdot 9$ inches, indicating a temperature of 134°. But inserting the value of $f - f'$ in the equation for the quantity evaporated in a given time, we have $\frac{a(p-f')}{2\sqrt{\cdot 266}} = \frac{a(p-f')}{1 \cdot 03}$ = the quantity evaporated; and when $p = 30$, and $f' = 3$, it is 26 a; or the operation may proceed 26 times as rapidly as seasoning in a covered shed, without the risk of splitting the timber more in the one case than in the other.

ON THE DECAY OF TIMBER.

Timber, when properly seasoned, is strong, tough, and elastic; but it does not long retain those properties in any state or situation. Timber is generally employed in situations where it is continually dry, where it is constantly wet, where it is alternately wet and dry, or where it is exposed to heat and continued moisture. The effect of each of these states is the next object of attention.

EFFECT OF CONTINUED DRYNESS.

350.—Timber that is constantly dry, or affected only by the small quantity of moisture it absorbs from the air in damp weather, has been known to last for seven or eight hundred years; but even in this state, time produces a sensible alteration in its properties; for it is found to lose its elastic and coherent powers gradually, and to become brittle. Hence it is unfit to sustain the action of variable loads, though in a state of rest it may endure an immense length of time.

EFFECT OF CONTINUED WETNESS.

351.—The wood of trees in its natural state is a very compound substance; a certain portion of its constituents is soluble in water; another part may be extracted by alcohol; and the part remaining, after being treated with alcohol, is the pure woody fibre, or lignin of chemists. After water has extracted all that is soluble by it from timber, it is obvious that while the timber continues immersed in water it may remain unchanged for an indefinite period; but if it be taken out and dried, it is found to be brittle and effete; or, to use the workman's expression, "its nature is gone;" and, as Dr. Sloane has observed of oak that had been buried in a wet situation, "it dries, splits, becomes light, and soon impairs."* But though oak timber taken from bogs is always found to be brittle and in a state of decay, fir from the same bog is often, if not always, in a much sounder state.

EFFECT OF ALTERNATE DRYNESS AND MOISTURE.

352.—When timber is exposed to the action of alternate dryness and moisture it soon decays. It has been already noticed, that repeated steeping and drying removes a sensible portion of the wood at each operation (see Articles 342 and 343); and it is evident, that at each drying a new portion of soluble matter is formed, which either did not before exist, or which is rendered soluble by a change in its principles. This conclusion is further established by Saussure, who found that wood the most completely freed of its soluble principles furnishes always, by maceration in water with the contact of air, infusions holding

* Evelyn's *Sylva*.

extractive matter dissolved.* The effect of this kind of decay may be observed in weather-boarding, fencing, and in any situation where wood is constantly exposed to the vicissitudes of the weather. When the timber has been thoroughly seasoned, painting or any kind of coating that is capable of resisting moisture, is the best means of preserving it from this kind of decay. (See Article 375.)

EFFECTS OF CONTINUED MOISTURE WITH HEAT.

353.—Wood, in common with other vegetable products, when exposed to a certain degree of moisture, and at a temperature not much under 45 degrees, nor too high to evaporate suddenly all the moisture, gradually decomposes. This decomposition is called putrefaction by chemical writers, but is called the rot in common language. It proceeds with most rapidity in the open air, but the contact of air is not absolutely necessary. Water is in all cases essential to the process; indeed it is a principal agent in all processes of decomposition.

As the rot goes on, certain gaseous matters are given out; chiefly carbonic acid gas and hydrogen gas.

Pure woody fibre alone undergoes this change slowly, but its texture is soon broken down, and it is easily resolved into new elements when mixed with substances more liable to change. "Any process," observes Sir H. Davy, "that tends to abstract carbonaceous matter from it must bring it nearer in composition to the soluble principles," and this is done by fermentation.† Hence it is that the sap-wood is of a more perishable nature than the heart-wood, for the sap-wood abounds more in saccharine and fermentible principles, and consequently sooner ferments. Dr. Darwin took part of the branch of an oak tree, cut in January, and divided it carefully into three parts, the bark, the albumen or sap-wood, and the heart-wood. These were each shaved, or rasped, and separately boiled in water, and then set in a warm room to ferment. The decoction of the sap-wood passed into rapid fermentation, and became acid; but not either of the other.‡

Duhamel tried some experiments to ascertain the effect of confining the sap in green timber; and found that the pieces thus confined soon exhibited signs of rapid decay: and therefore he strongly recommends a free space for the circulation of air round the ends of joists and beams, instead of building them in the wall. Duhamel also tried the effect of covering the external surface of timber with paint, tar, and pitch; and found that it contributed much to the durability of dry or well-seasoned timber, but hastened the decay of green and unseasoned timber.§

Quicklime, when assisted by moisture, has a powerful effect in hastening the decomposition of wood, in consequence of its abstracting carbon. Mild lime (carbonate of lime) has not this effect. But mortar requires a considerable time to bring it to the state of mild lime; therefore, bedding timber in mortar, or building it in walls where it will long remain in a damp state in contact with mortar, is very injurious, and often the cause of rapid decay. Wood in a perfectly dry state does not appear to be injured by dry lime: of this we have

* Dr. Murray's *System of Chemistry.*
† *Agricultural Chemistry.*
‡ *Phytologia.*
§ Chapman on *Preservation of Timber.*

examples in plastering-laths, which are generally found sound and good in places where they have been dry. Lime also protects wood from worms.

Volatile and fixed oils, resins, and wax, are equally as susceptible of decay as woody fibre under the same circumstances; hence we see the impropriety of attempting to protect wood in any situation where the coat of paint, &c., cannot be renewed from time to time: and also that woods abounding in resinous matter cannot be more durable than others.

Decay sometimes commences in the growing tree; for when it has stood beyond a certain age, decay at the heart has generally made some progress. (See Article 336.) This has often been observed in large girders of yellow fir, which have appeared sound on the outside, but by removing some of the binding joists have been found completely rotten at the heart.* It is on this account that the practice of sawing and bolting girders is recommended. (See Article 140, Section III.)

It is usual to divide the rot into two kinds, the *wet rot* and the *dry rot;* the main distinction between them being, that in the one the gaseous products are evaporated, and in the other the greater part of them form into a new combination which is a species of fungus. Both, in a chemical sense, are produced by precisely the same causes, with this exception, that a free evaporation, determines it to be the wet rot; a confined space, or imperfect evaporation, renders it the dry rot, as timber must be decomposed in becoming the food of a plant; it is evidently the same with the putrefaction of chemists with different products. It is said that the decay of a post placed in the ground, or in water, is an example of the wet rot; and it is assumed that the parts undergoing the process of decay are alternately wet and dry; but the fact is, they are constantly supplied with that degree of dampness which is essential to putrefaction. For timber being composed longitudinally of an assemblage of pipes or tubes, it is only necessary that one end of a log of wood should be placed in a damp or wet situation, to occasion the moisture to be conveyed to the opposite end by capillary attraction. Prevent a free change of atmospheric air, and a post so circumstanced, it is well known, would be affected with the dry rot. Hence it appears that those writers are mistaken who assert that they are essentially different, both in the symptoms, the progress, and the causes.

When only the external part of a beam has been seasoned, and the sap has never been evaporated from the internal part, the rot will be an internal disease; and where an internal decay of this kind is found, it proves that the timber has never been properly seasoned. Mr. Bowden, in the plate to his *Treatise on the Dry Rot*, gives figures of such a piece; it appears to be of common occurrence; and it is evident from such examples of decay, that the want of due time and attention in seasoning is one of the chief causes of the rapid decay of ships. In Mr. Bowden's specimen the exterior part, to the depth of 2 inches from the outside, was as sound as any wood could possibly be; but the central part was filled with a fine white, thread-like vegetation, extending within the above-mentioned 2 inches of the exterior surface, and uniting in a thick fungous coat at the end of the piece;† thus showing the depth to which the seasoning had been effected.

* The author observed an instance of this kind in the repairs at Kenwood (the seat of the Earl of Mansfield), in 1815; and similar ones at some other places since that time. Major Jones, of the Royal Engineers, has also stated, that on one occasion he was called upon to report on the state of a building in Malta; that the timbers had every external appearance of being sound; but on being bored with an augur, they were found internally in a total state of decay.

† *Treatise on the Dry Rot.*

354.—In the first stages of rottenness the timber swells and changes colour, is often covered with mucor or mouldiness, and emits a musty smell. Where the rottenness is internal, or the timber is in a confined space, a new substance is formed between the fibres, of a spongy consistency, resembling the external coat of a mushroom; and the substance itself has been ascertained to belong to the order Fungi of the Cryptogamia class of plants.

When the fungus first appears on the sides and ends of timbers, it covers the surface with a fine white and delicate vegetation, called by shipwrights a mildew. These fine shoots afterwards collect together, and the appearance then may be compared to hoar-frost, and increases rapidly, assuming gradually a more compact form, like the external coat of a mushroom, but spreads alike over wood, brick-work, stone, and plastering, in the form of leaves, being larger or smaller most probably in proportion to the nutriment the wood affords. The colours of the fungus are various: sometimes white, greyish white, with violet; often yellowish brown, or a deep shade of fine rich brown.

It has been considered a question of some importance to determine how fungi are propagated, or from what they originate; but as such an inquiry can be attended with little if any advantage in preventing the rot, it appears to be better to consider it only so far as it is a chemical change, leaving the question of their origin to the curious, as well as the distinction of the species of fungi.

In the more advanced stages of rottenness the woody fibres contract lengthwise, and show many deep fissures across the fibres, similar to a piece of wood scorched by the fire. The woody fibres appear to retain their natural form, but easily crumble into a fine powder. In oak this powder is of a fine snuff-brown colour.

The fungus, when it spreads upon the surface of the wood, often becomes of a considerable size, sometimes spreading over the adjoining walls, and ascending to a considerable height.

The decayed state of a barn floor is thus described by Mr. B. Johnson: "An oak barn floor which had been laid twelve years began to shake, and on examination was found to be quite rotten in various parts. The planks, $2\frac{1}{2}$ inches in thickness, were nearly eaten through, except the outside, which was glossy, and apparently without blemish. The rotten wood was partly in the state of an impalpable powder, of a snuff colour; other parts were black, and the rest clearly fungus. No earth was near the wood."*

355.—In timber of the same kind, that of the most sappy and rapidly grown trees is the most subject to decay. The wood of trees from the close forests of Germany or America is more subject to it than that of trees grown in more open situations; and it is remarked by Mr. Barrow, that "the timber brought from America in the heated hold of a ship, is invariably covered over, on being landed, with a complete coating of fungus." Consequently, the timber must be infected with the seeds of decay before it is brought into use. Also the custom of floating timber in docks and rivers injures it very much: it would be better to sink it completely under water, as to half-immerse in water is the worst situation it can be placed in.

356.—Though moisture be essential to the progress of decay, absolute wetness will prevent it, especially at a low temperature. In ships this has been particularly remarked, for that part of the hold of a ship which is constantly washed by the bilge-water is never affected by

* *Transactions of the Society of Arts, &c.*, vol. xxi.

dry rot.* Neither is that side of the planking of a ship's bottom which is next the water found in a state of decay, even when the inside is quite rotten, unless the rot has penetrated quite through from the inside.

357.—Warmth and moisture are the most active causes of decay; and provided the necessary degree of moisture be present, the higher the heat the more rapid is its progress. In warm cellars, or in any close confined situations where the air is filled with vapour without a current to change it, the rot proceeds with astonishing rapidity, and the timber-work is destroyed in a very short time. The bread-rooms of ships, behind the skirting and under the wooden floors or the basement stories of houses, particularly in kitchens or other rooms where there are constant fires, and in general in every place where wood is exposed to warmth and damp air, the dry rot will soon make its appearance.

358.—All kinds of stoves are sure to increase the disease, if moisture be present. The effect of heat is also evident from the rapid decay of ships in hot climates. And the warm moisture given out by particular cargoes is also very destructive, such as cargoes of hemp, pepper, and cotton.†

359.—Building timber into new walls is often a cause of decay, as the lime and damp brick-work are active agents in producing putrefaction, particularly where the scrapings of roads are used instead of sand for mortar. Hence it is that bond-timbers, wall-plates, and the ends of girders, joists, and lintels, are so frequently found in a state of decay. The old builders used to bed the ends of girders and joists in loam, instead of mortar, as is directed in the Act of Parliament for rebuilding the city of London, after the great fire.‡ In this place it may not be amiss to point out the dangerous consequences of building walls so that their principal support depends on timber. The usual method of putting bond-timber in walls is to lay it next the inside; this bond often decays, and of course leaves the wall resting only upon the external course or courses of bricks; and fractures, bulges, or absolute failures are the natural consequences. This evil is in some degree avoided by placing the bond in the middle of the wall, so that there is brick-work on each side, and by not putting continued bond for nailing the battens to. In bad foundations it was at one time very common to lay planks to build upon: unless these planks be absolutely wet, they are certain to rot in such a situation, and the walls settle, and most likely irregularly, which will rend the building to pieces. Instances of such kinds of failure frequently occur: it was found necessary to underpin three of the large houses in Grosvenor Place at an immense expense. In one of these houses the floors were not less than 3 inches out of level: the planking had been 7 inches thick, and was most of it completely rotten. It was of yellow fir. A like accident happened to Norfolk House, St. James's Square, where oak planking had been used.

But if the powerful lateral pressure of flat arches were avoided, so many ties or bond-timbers would not be necessary. The improper use of arches produces more fractures in buildings than any other cause. Nothing can be more absurd than the construction of fronts of London houses; they exhibit a continued series of stretchers and ties. Each range of arches is a line of stretchers, and the bond and wall plates are the ties; and as the arches are close-jointed and well fitted on the outside, but open-jointed

* Bowden's *Treatise on the Dry Rot.* † Chapman on *Preservation of Timb r.*

‡ 19 Charles II, cap. 3.

and indifferently built in the inside, when the building settles it has a strong tendency to bulge outwards. Thus timber ties are necessary to secure an ill-constructed wall, which consequently cannot be more durable than the timber.

As an example of the danger of trusting to timber in supporting heavy stone- or brick-work, the failure of the curb of the brick dome of the church of St. Mark, at Venice, may be cited. This dome was built upon a curb of larch timber, put together in thicknesses, with the joints crossed, and was intended to resist the tendency which a dome has to spread outwards at the base. In 1729 a large crack and several smaller ones were observed in the dome. On examination the wooden curb was found to be in a completely rotten state; and it was necessary to raise a scaffold from the bottom to secure the dome from ruin. After it was secured from falling, the wooden curb was removed, and a course of stone, with a strong bond of iron, was put in its place.*

The bad effects resulting from damp walls is still further increased by hasty finishing. To enclose with plastering and joiner's work the walls and timbers while they are in a damp state, is the most certain means of causing the building to fall into a premature state of decay.

360.—There is another cause that affects all wood most materially, which is the application of paint, tar, or pitch, before the wood has been thoroughly dried. The nature of these bodies prevents all evaporation, and confines the internal moisture, which is the cause of sudden decay. Mr. Bramley remarks, that both oak and fir posts were brought into a premature state of decay by their having been painted prior to a due evaporation of their moisture; and painting affords no protection to timber against dry rot.

On the other hand, the doors, pews, and carved work of many old churches have never been painted, and yet they are often found to be perfectly sound, after having existed above a century. In Chester, Exeter, and other old cities, where much timber was formerly used, even for the external parts of buildings, it appears to be sound and perfect, though black with age, and has never been painted.

Mr. Semple mentions an instance of some field-gates made of home fir, part of which, being near the mansion, were painted, while the rest, being in distant parts of the grounds, were not painted. Those which were painted soon became quite rotten, but the others which were not painted continued firm.†

Painted floor-cloths are very injurious to wooden floors, and soon produce rottenness in the floors that are covered with them; as the painted cloth prevents the access of atmospheric air, and retains whatever dampness the boards may absorb, and therefore soon causes decay. Carpets are not so injurious, but still assist in retarding free evaporation.

* Rondelet, *L'Art de Batir;* or *Encyclopédie Méthodique, Dict. Architecture*, Art. "Coupole."

† Treatise on *Building in Water.*

ON THE PREVENTION OF DECAY.

361.—Having now noticed the chief causes of decay, its prevention becomes the next object of inquiry.

A proper seasoning of timber is the best means of securing it against decay, whatever the cause of the decay may be: and in addition to what has been already said on seasoning (Arts. 341 to 347), it only remains to add, that the seasoning must be complete to be effectual. The time required for a complete seasoning depends on the size of the pieces; and some valuable experiments on this subject have been made by Mr. Laslett. (See Art. 341.)

362.—But, however well timber may be seasoned, if it be employed in a damp situation, decay is the certain consequence; therefore it is most desirable that the neighbourhood of buildings should be well drained, which would not only prevent the rot, but also increase materially the comfort of those who reside in them. The drains should be made water-tight wherever they come near to the walls; as walls, particularly brick walls, readily draw up moisture to a very considerable height. Earth should never be suffered to rest against walls, and the sunk stories of buildings should always be surrounded by an open area, so that the walls may not absorb moisture from the earth. To prevent moisture rising from the foundation, some substance that will not allow it to pass should be used at a course or two above the footings of the walls. Sheets of lead or copper have been used for that purpose. To lay a few courses of slates or slaty stones that do not absorb much moisture and bedded in cement, would be useful; but a better method is to build a few courses in height with Roman or Portland cement, instead of common mortar, and upon the upper course to lay a bed of about an inch in thickness of cement. As moisture does not penetrate this cement, it is an excellent material for keeping out wet; and it is also a great improvement to a brick building to stucco it on the outside with any cement which keeps out moisture, as brick absorbs quickly all the moisture which comes in contact with it, and retains it for a length of time.

363.—The walls and principal timbers of a building should always be left for some time to dry after it is covered in. This drying is of the greatest benefit to the work, particularly the drying of the walls: and it also allows time for the timbers to get settled to their proper bearings, which prevents after settlements and cracks in the finished plastering. It is sometimes said that it is useful, because it allows the timber more time to season; but when the carpenter considers that it is from the ends of the timber that much of its moisture evaporates, he will see the impropriety of leaving it to season after it is framed, and also the cause of framed timbers of unseasoned wood failing at the joints sooner than in any other place. No parts of timbers require the perfect extraction of the sap so much as those that are to be joined.

364.—Also, when the plastering is finished, a considerable time should be allowed for the work to get dry again, before the skirtings, the floors, and other joiner's work be fixed. Drying will be much accelerated by a free admission of air, particularly in favourable weather.

When a building is thoroughly dried at first, openings for the admission of fresh air are not

necessary where the precautions against any new accessions of moisture have been effectual. Indeed, such openings only afford harbour for vermin, as the current of air through them is very seldom capable of carrying off any considerable degree of moisture; for it is well known that air will not move in a horizontal direction without a more considerable change of density than can be obtained in such situations. The roof over the Egyptian Hall in the Mansion House, London, has a space of 2 feet in depth all round it, for the free circulation of air between the roof and ceiling; and in old Gothic buildings the roofs were generally well ventilated, which must have added much to their durability. But the construction of floors does not admit of the same facilities, and therefore floors are more subject to decay; for, as Mr. Papworth very justly observes, "should the air absorb less moisture from the fungus than the timber affords to its vegetation, the air will then increase the disease, and draw into fuller growth the fungus it has not the power to destroy; but if dry air be admitted in a quantity adequate to cause that absorption, it will necessarily exhaust and destroy the fungus."* But such a quantity of dry air cannot, from the nature of the structure, be made to pass between the timbers of a floor, though sufficient may be admitted to accelerate its decay.

365.—In floors next the ground we cannot easily prevent the access of damp, but this should be done as far as possible. All vegetable mould should be carefully removed, and if the situation admits of it, a considerable thickness of dry materials, such as brickbats, dry ashes, &c., but not lime, should be laid under the floor, and over these a coat of smith's ashes, or of pyrites, where they can be procured. The timber for the joists should be well seasoned; and it is advisable to cut off all connection between wooden ground-floors and the rest of the wood-work of the building.

366.—It was long a general opinion that timber might be secured against the dry rot by impregnating it with some substance that would resist putrefaction: this opinion produced many schemes, and led finally to that recommended and patented by Mr. Kyan. (See Kyan's process, Art. 370.)

Common salt (chloride of sodium) is found to protect the timber impregnated with it, when the proportion of salt is considerable. The large wooden props which support the roofs of the salt mines in Hungary, and are perpetually moistened with salt water trickling down them, are said to have suffered no decay for many centuries;† and the incrustations of salt upon the timbers of vessels employed in carrying salt-fish preserve them a great number of years.‡ There are, however, strong objections to using solutions of salt, unless it be where it is of no importance whether the wood be dry or wet; for the attraction of salt for moisture would keep the wood continually wet if moisture should be present.

Sea-water has been found effectual in clearing timber of fungus, by immersing it for several months. A ship called the *Eden* was cleared of every trace of fungus by remaining eighteen months under water.§ But unless a solution of salt, so strong as to be objectionable from its attraction of water, could be used, there appears to be no well-grounded hope of its being useful.

367.—*Sulphate of iron* (commonly called green copperas) appears to be more likely to answer the purpose. Wood boiled for three or four hours in a solution of sulphate of iron,

* Essay on the *Causes of the Dry Rot.*

† Darwin's *Phytologia.*

‡ Bowden on the *Dry Rot.*

§ *Transactions of the Society of Arts*, vol. xxxvi.

and then kept some days in a warm place to dry, becomes so hard and compact that moisture cannot penetrate it. In the Swedish Transactions it is recommended for preserving the wood of wheel carriages from decay;* and Mr. Chapman observes, that the wooden vessels in which copperas is crystallised become exceedingly hard, and not subject to decay. Mr. Chapman strongly recommends immersing timber in a solution of this salt on a large scale, in order to be used for ship-building.

368.—Dr. Darwin supposes that the rot in wood might be entirely prevented by soaking dry timber first in lime water till it has absorbed as much of it as possible, and then, after it is dry, soaking it in a weak solution of sulphuric acid in water. This acid will combine with the lime in the bores of the timber, and form gypsum (sulphate of lime), and preserve it from decay if kept dry.† The benefit perhaps would not be equivalent to the trouble of this process.

Boiling in alkalies has been proposed; but as the alkalies dissolve and decompose the woody fibre, this process cannot be attended with advantage.

369.—Quicklime, it has been already stated (Art. 359), assists putrefaction when aided by moisture. But where a great quantity of fresh quicklime is present, often in contact with the wood, so as to preserve it in a perfectly dry state, by the rapid absorption of water, this hardens the sap, and renders the wood very durable. Of this effect of lime Mr. Chapman had an opportunity of seeing proofs in the vessels employed in the Sunderland lime trade, some of which were forty years old, and very sound.‡

KYAN'S PROCESS FOR THE PRESERVATION OF TIMBER FROM DRY ROT.

370.—From the preceding articles it will be seen that the idea of preserving timber from rot by impregnating it with certain substances, is not of itself new; nor is even the employment of the substance itself recommended by Kyan, viz., corrosive sublimate, a novel application; for it will be seen, referring to Art. 374, that Sir H. Davy had before recommended a wash of a weak solution of this substance to check the progress of the rot in places where it had commenced, and which were under repair. Indeed corrosive sublimate had been long known as an anti-destructive, and has been, as such, long employed by anatomists to prevent the decay of the most delicate organic tissues and other parts liable to putrescence; and by the application of this metallic preparation, they have been prevented from going to decay, and have been preserved for very long periods.

Kyan's process consists in applying this substance to timber for the prevention of rot; that is, causes of decay, arising either from the action of the seed of cryptogamous plants vegetating in the wood, or from the presence of the albuminous parts of the tree. In order to carry it into practice, large trunks of wood are prepared with cross-beams, in order to wedge down the timbers placed therein for immersion; that is, the timber which is to undergo the process is first placed therein, under those beams, and wedged down so as to prevent it from rising when the fluid, impregnated with the corrosive sublimate, is introduced. In this

* Neuman, quoted by Chapman, on *Preservation of Timber.*

† *Phytologia.*

‡ Chapman on *Preservation of Timber.*

state it remains for about a week. The fluid is then pumped off, the timber taken out and dried, and is thus considered to be secure against the action of the destructive vegetation and decomposition which have been found so injurious to every kind of timber structure, from the smallest closet to the largest man-of-war. The same process is also adopted for preserving various substances not composed of wood, such as canvas, cotton, hemp, ropes, &c.

371.—The inventor having satisfied himself of the efficacy of this process laid his plan before the Admiralty, who were naturally desirous of some proof of its effect, and the inventor was therefore referred to the officers of Woolwich Dockyard, where certain prepared and similar unprepared specimens were placed in what is called the fungus pit. Here the several specimens remained for three years. They were then taken out; and it was found, generally, that the prepared specimens were sound, while those unprepared were in various stages of decay. One specimen was a piece of timber which came out at the end of the above period as sound as it went in; but the unprepared timber had decayed up to the very joint: no part of it had been left; it had decayed and become rotten throughout. These and similar experiments on timber, canvas, rope, &c., were made in the same establishment, and with similar results.

372.—There could be no doubt, from these experiments, that the process the different articles had undergone acted as a preservative from the rot, under the circumstances in which they had been placed; and the only doubt which seemed to hang over the inquiry was, whether the effect was permanent or temporary: if the effect were due to a simple impregnation, it might, under different circumstances, be removed, whereby the timber would be left in its original state, while a noxious atmosphere might be generated, which would be extremely injurious to health in many cases, and particularly in ships of war. It is therefore highly satisfactory to state that Dr. Faraday decided from experiment that the effect is not that of a mere mechanical impregnation; but that a chemical combination takes place between the corrosive sublimate and the albuminous matter of the wood, forming thereby a new compound. This question being thus settled, we may next inquire to what depth the effect has taken place; and it appears that hitherto it has not been traced to more than about half an inch from the surface: and it remains, therefore, perhaps still doubtful whether it will be found fully effective in large timbers. These indeed will be protected from contagion from other decayed wood; but, for anything at present shown, the rot may commence in them internally; still, however, if even this should be the case, much has undoubtedly been effected.

373.—Some question having arisen as to the effect of Kyan's process upon the strength of the timber, the following experiments were made by Captain Alderson, Royal Engineers. Two pieces of ash, only parted by the saw, were formed, 2 inches square and 3 feet long; and two pieces of Christiania deal of the same dimensions; one of each was prepared, the other two unprepared, and they were then submitted to a trial of transverse strength and stiffness, at a clear bearing distance of 34 inches, as stated in the following table:—

Names of the Wood.		Specific gravity.	Weight that deflected the wood one inch.	Weight that broke the piece.
			lbs.	lbs.
Ash	Not saturated ...	786	775	2,231
	Saturated	780	999	2,175
Christiania deal	Not saturated ...	441	663	1,279
	Saturated	417	719	1,167

From these experiments, it would appear that the process diminishes both the specific gravity and the strength of the timber, but that it increases its rigidity.

REPAIRS OF BUILDINGS AFFECTED WITH THE ROT.

374.—To cure the rot is very difficult, and would be nearly, if not quite, as expensive a process as to put in anew the timbers affected by it; but when new timber is put in, the old parts and the walls should have every particle of fungus removed from them, or killed by some wash for that purpose. External washes perhaps are not much further useful than so far as they hinder infection; but to produce that effect they are perhaps the best application, because they can be applied with safety. A high degree of heat, that is, about 300°, would destroy all power of reproduction, but it cannot so well be applied: nevertheless, where pieces of wood are not materially injured by the rot, an oven might be contrived to expose them to a strong heat, which would destroy all vegetable life in the fungus, and they might then be washed with some of the solutions mentioned below, and used again with perfect safety.

A solution of corrosive sublimate (bichloride of mercury) would answer very effectually as a wash. It was proposed by Sir H. Davy. A very weak solution does not produce the desired effect; Chapman says there should be an ounce of corrosive sublimate to a gallon of water, and it should be laid on hot. No other metallic solution should be mixed with it.

A solution of sulphate of copper (commonly called blue vitriol), in the proportion of about half a pound of sulphate of copper to one gallon of water, used hot, makes an excellent wash, and is cheaper than the preceding one.

A strong solution of sulphate of iron is sometimes used, but is not so effectual as that of copper; and sometimes a mixture of the two solutions has been used.

Coal tar, or *creosote*, is found beneficial; but its strong smell is a great objection to its use; where the smell is not of importance, it would assist in securing new timber which had been previously well dried.

Charring new wood can only be expected to prevent infection; as we have seen (Art. 353) that decay may begin at the centre, and proceed without ever appearing at the surface of the beam: and therefore if timber be not well seasoned, no permanent good can be obtained from charring.

TO PRESERVE WOOD EXPOSED TO THE WEATHER.

375.—When timber is exposed to the alternate action of dryness and moisture, the best means of securing it from moisture is the protection of the surface by a coat of some substance that moisture will not penetrate.

The Dutch, for the preservation of their gates, drawbridges, sluices, and other large works of timber, which are exposed to the sun and perpetual injuries of the weather, coat them with a mixture of pitch and tar, upon which they strew small pieces of cockle and other shells, beaten almost to powder, and mingled with sea-sand, or the scales of iron beaten small and sifted, which protects them in a most excellent manner.

Upon common painting, sanding is an excellent practice, where it is exposed to the weather, being much more durable than painting alone.

Mr. Chapman proposes a composition which possesses the properties of impenetrability to moisture and flexibility. It consists in applying a paint made of sub-sulphate of iron (the refuse of the copperas pans), ground up with any cheap oil, and rendered thin with coal-tar oil, in which a little pitch has been dissolved. In the neighbourhoods of Newcastle and Glasgow the refuse of the copperas pans may be easily procured. Impregnation with *creosote*, which is one of the products obtained from coal-tar, is frequently adopted for preserving timbers exposed to weather, as in the case of railway sleepers.

Immersing timber for several days in a solution of *chloride of zinc* has been largely adopted in the Government dockyards, and is found both beneficial to the wood and a preventative of decay. This process was the subject of a patent by Sir W. Burnett in 1838.

Another method of protecting timber is described by Mr. Semple, which appears to be so well calculated for the purpose, that in cases where it can be applied a better cannot be employed. It is described in his own words as follows: "After your work is tried up, or even put together, lay it on the ground with stones or bricks under it to about a foot high, and burn wood (which is the best firing for that purpose) under it until you thoroughly heat and even scorch it all over; then, whilst the wood is hot, rub it over plentifully with linseed oil and tar, in equal parts, well boiled together, and let it be kept boiling whilst you are using it; and this will immediately strike and sink (if the wood be tolerably seasoned) 1 inch or more into the wood, close all the pores, and make it become exceedingly hard and durable, either under or over water."*

No composition should, however, be applied till the timber has been well seasoned: for to enclose the natural juices of the wood is to render its rapid decay certain.

ON THE PREVENTION OF THE RAVAGES OF WORMS AND INSECTS.

376.—Besides the decay of its parts, timber is subject to be destroyed by various worms and insects. Some woods are more subject to be destroyed by them than others; such as alder, birch, and in general all soft woods, of which the juices are of a saccharine nature.

* Semple on *Building in Water*.

Against the common worm, oil of spike is said to be an excellent remedy, and the oil of juniper, or of turpentine, will prevent them in some degree. A free use of linseed oil is a good preventive, and so is a covering of copal varnish; but these can be applied to small articles only.

Evelyn recommends sulphur which has been immersed in aquafortis (nitric acid), and distilled to dryness, which, being exposed to the air, dissolves into an oil. The parts to be secured from the worm are to be anointed with this oil, which does not give an unpleasant odour to the wood.

Lime is an excellent preservative against the worm, and sap-wood should always be impregnated with it when used in a dry situation.

As worms do not attack bitter woods, soaking wood in an infusion of quassia has been tried, which is said to have the desired effect.

377.—The bottoms of ships, and timbers exposed to the action of the sea, are often destroyed by the pipe-worm, or *teredo navalis* of naturalists. This creature is very small when first produced from the egg, but soon acquires a considerable size, being often 3 or 4 inches in length, and sometimes increases to a foot or more in length. Its head is provided with a hard calcareous substance, which performs the office of an augur, and enables it to penetrate the hardest wood. When a piece of wood, constantly under water, is occupied by these worms, there is no sign of damage to be seen on the surface, nor are the worms visible until the outer part of the wood is broken or cut away; yet they lie so near the surface as to have an easy communication with the water by a multitude of minute perforations. They were originally brought from India to Europe.

Wood is eaten by them until it becomes like a honeycomb, yet there is an evident care in these creatures never to injure one another's habitations, for the divisions between the worm-holes are entire, though often extremely thin. The fir and alder are the two kinds of wood they seem to destroy with the greatest ease, and in these they grow to the greatest size. In oak they make slower progress, and appear smaller, and not so well nourished.

They never touch bitter woods, and in solid or hard woods they make slow progress. Charring the surface of wood is not found to be of any use.

A mixture of lime, sulphur, and colocynth, with pitch, is found to be a protection to boards and the like. And rubbing the wood with poisonous ointments is a means of destroying them.* A mixture of tar, pitch, and the animal hair separated in tanning was formerly applied, with a sheathing of wood to keep it on, and lately the hair has been felted to apply under copper. A covering of thin copper with tarred felting between it and the wood, is the best protection for the bottoms of ships from all marine animals.

A species of tholas (*tholas striata*) is another animal which is very destructive, not to timber only, but to stones, clay, &c., in water; they make their attack in a similar manner to the pipe-worm, by burrowing when young, the entrances of the holes only about one-fourth of an inch in diameter; and the animal, increasing in growth as it advances, forms a larger hole, till it arrives at maturity, when it ceases to bore; it

* *Rees's Cyclopædia*, Art. "Teredo."

derives its sustenance from the water, and never bores so far that it cannot reach the water with its proboscis.*

The Lepisma is also a destructive little animal, which begins to prey on wood in the East Indies as soon as it is immersed in sea water. The unprotected bottom of a boat has been known to be eaten through by it in three or four weeks: sheathing with copper or covering with felt are the most certain means of protection against all these marine animals.

Coal-tar, and its derivative, *creosote*, is also a good protection against their depredations. The pores of the wood should be saturated as far as possible with it; and perhaps corrosive sublimate might be used with advantage, by saturating the wood with a solution of it, and letting it dry before the tar be laid on.

Whale oil is stated to be an effectual remedy, and has been successfully employed.†

378.—There is another kind of worm which is very destructive to timber, which Smeaton observed in Bridlington piers. The wood of these piers, he says, is destroyed by a certain species of worm, differing from the common worm whereby ships are destroyed. "This worm appears as a small white soft substance, much like a maggot; so small as not to be seen distinctly without a magnifying glass, and even then a distinction of its parts is not easily made out. It does not attempt to make its way through the wood longitudinally, or along the grain, as is the case with the common ship worm: but directly, or rather a little obliquely, inward. They do not appear to make their way by means of any hard tools or instruments, but rather by some species of dissolvent liquor, furnished by the juices of the animal itself. The rate of progression," he was informed, "is, that a 3-inch oak plank will be destroyed in eight years by their action from the outside only."‡ Fir is more subject to be destroyed by this worm than oak.

To prevent the destructive effects of these worms, Smeaton recommended that the timbers of the piers should be squared, and made to fit as close together as possible; to fill all the openings left with tar and oakum, and level the face, and cover it with sheathing, as ships are covered.

These worms do not live except where they have the action of the water almost every tide; nor do they live in the parts covered with sand. The wooden piles of embankments and sea-locks suffer much from these worms, and in the sea-dykes of Holland they cause very expensive annual repairs.

The remedies that resist the ship worm would no doubt be effectual against these.

379.—The termite or white ant (a species of the genus *termes*, and of the aptera order of insects in the Linnæan system) is represented by Linnæus as the greatest calamity of both Indies, because of the havoc they make in all buildings of wood, in utensils, and in furniture; nothing but metal or stone can escape their destructive jaws. They frequently construct nests within the roofs and other parts of houses, which they destroy if not speedily extirpated. The larger species enter under the foundations of houses, making their way through the floors, and up the posts of buildings, destroying all before them.§ And so little is seen of their operations, that a well-painted building is sometimes found to be a mere shell.

* Wilcox, *Papers on Naval Architecture*, vol. i.

† Chapman on *Preservation of Timber*.

‡ Smeaton's *Reports*.

§ *Rees's Cyclopædia*, Art. "Termite."

Corrosive sublimate is highly poisonous to these ants; therefore, to impregnate the timber with a solution of it would prevent their ravages. Arsenic is also very destructive to them, and they do not destroy wood impregnated with oil, particularly essential oils.* Thunberg found cajeput oil effectual in destroying the red ants of Batavia; he used it to preserve his boxes of specimens from them. When ants were put into a box anointed with this oil they died in a few minutes.†

ON THE DURABILITY OF TIMBER.

380.—The carpenter who feels any delight in the progress of his art cannot be insensible to the advantage of giving durability to his materials; nor yet be uninterested in any inquiry into the probable extent of their duration. Not that his fame as an artist rests solely on the extent of their duration; for while his productions are worthy of imitation, the remembrance of them will be preserved by the engraver's art as long as there shall be men capable of paying a just tribute to the memory of departed merit. The French army, in 1799, destroyed the celebrated bridge across the Rhine at Schaffhausen; but the fame of Grubbenmann the carpenter will long continue; and the form of that excellent specimen of the art will only cease to be remembered when carpentry itself no longer exsist.

It must also be remembered, that to give durability to his materials is one branch of the carpenter's art; and that to be defective in this particular is as much to his discredit as to be unacquainted with the geometrical or mechanical principles of carpentry.

As examples of the duration of timber, we have collected the following notices; and must leave the subject to be extended by those who have better means of rendering it more complete.

Of the durability of timber in a wet state, the piles of the bridge built by the Emperor Trajan across the Danube are an example. One of these piles was taken up, and found to be petrified to the depth of three-fourths of an inch; but the rest of the wood was little different from its ordinary state, though it had been driven more than sixteen centuries.‡

The piles under the piers of London Bridge had been driven about 600 years, and from Mr. Dance's observations, in 1746, it does not appear that they were materially decayed;§ indeed they were found to the last sufficiently sound to support the massy superstructure. They were chiefly of elm.

381.—We have also some remarkable instances of the durability of timber when buried in the ground. Several ancient canoes have been found in cutting drains through the fens in Lincolnshire, which must have lain there for many ages. In the *Journal of Science*, &c., published at the Royal Institution, one of these canoes is described, which was found at the depth of 8 feet below the surface of the ground. It was 30 feet 8 inches long, and 3 feet wide in the widest part, and appears to have been hollowed out of an oak tree of remarkably fine free-grained timber.‖

* Chapman on *Preservation of Timber*.
† Thunberg's *Travels*.
‡ Buffon, *Preuves de la Théorie de la Terre*.
§ Hutton's *Tracts*.
‖ *Journal of Science*, &c., vol. i.

Also, in digging away the foundation of old Savoy Palace, London, which was built 650 years ago, the whole of the piles, consisting of oak, elm, beech, and chestnut, were found in a state of perfect soundness; as also was the planking which covered the pile-heads. Some of the beech, however, after being exposed to the air a few weeks, though under cover, had a coating of fungus spread over its surface.

382.—On opening one of the tombs at Thebes, Belzoni discovered two statues of wood, a little larger than life, and in good preservation; the only decayed parts being the sockets to receive the eyes. The wood of these statues is probably the oldest in existence that bears the traces of human labour.

A continued range or curb of timber was discovered in pulling down a part of the Keep of Tunbridge Castle, in Kent, which was built about 700 years ago. This curb had been built into the middle of the thickness of the wall,* and was no doubt intended to prevent the settlements likely to happen in such heavy piles of building; and therefore is an interesting fact in the history of constructive architecture, as well as an instance of the durability of timber.

In digging for the foundations of the present house at Ditton Park, near Windsor, the timbers of a drawbridge were discovered about 10 feet below the surface of the ground; these timbers were sound, but had become black. Hakewell says, that Sir John de Molines obtained liberty to fortify the Manor-house at Ditton, in 1396;† and it is most probable the drawbridge was erected soon after that time; and accordingly the timber had been there about 400 years.

383.—The durability of the framed timbers of buildings is also very considerable. The trusses of the old part of the roof of the old Basilica of St. Paul, at Rome, were framed in 816, and were sound and good in 1814, a period of nearly a thousand years. These trusses were of fir.‡

The timber-work of the external domes of the Church of St. Mark at Venice is more than 800 years old, and is still in a good state.‡ And Alberti observed the gates of cypress to the Church of St. Peter at Rome, to be whole and sound after being up 550 years.

The inner roof of the chapel of St. Nicholas, King's Lynn, Norfolk, is of oak, and was constructed about 450 years ago.§

Daviller states, as an instance of the durability of fir, that the large dormitory of the Jacobin's Convent at Paris had been executed in fir, and lasted 400 years.

The timber roof of Crosby Hall, in London, was executed about 360 years ago; and the roof of Westminster Hall, which is of oak, is now about 450 years old.

The rich carvings in oak, which ornamented the ceiling of the king's room in Stirling Castle, are many of them still in good preservation. It is nearly 300 years since they were executed, and they remained in their original situation till a part of the roof gave way in 1777, when the whole was removed, and has since been dispersed among the collectors of curious relics of old times.‖

* King's *Observations on Ancient Castles.*

† *History of Windsor.* ‡ Rondelet, *L'Art de Bâtir.* § Britton's *Architect. Antiq.*

‖ *Lacunar Strevelinense.* This work is a collection of engravings of carvings; and some of the borders might furnish useful hints to artists.

Moreton Hall, in Cheshire, where the staircase winds round the trunk of an immense oak tree, and the building itself is chiefly constructed of wood, has now existed 250 years.

Mr. Britton describes an old house at Islington, constructed chiefly of wood, which he has ascertained to be about 200 years old. Such houses are still sufficiently common; indeed most of our *ornamented* timber fronts are considerably older. The city of Beauvais is full of rich specimens in a style 400 years old, and a few of the same age exist in Rouen, Salisbury, and Shrewsbury.

Other notices of extraordinary durability will be found in the descriptions of the different kinds of wood. But enough already has been collected to show that timber is very durable where nothing more than ordinary means have been used to render it so; that is, nothing more than judicious selection and good seasoning. Every permanent support should be a good and sound piece of timber: inferior kinds should be used for temporary purposes, and where no strain occurs, and consequently where they can be easily renewed without injury to the strength of the building.

Mr. Barrow, in writing on this subject, very judiciously remarks, "that the felling of timber while young and full of vigour, making use of the sap-wood, and applying it to ships and buildings in an unseasoned state, have no doubt contributed to make the disease of dry rot infinitely more common and extensive than it was in former times, when our ships were hearts of oak, and when, in our large mansions, the wind was suffered to blow freely through them, and a current of air to circulate through the wide space left between the panelled wainscot and the wall. In those old mansions which yet remain, and in the ancient cathedrals and churches, we find nothing like dry rot, though perhaps

> ..... 'perforated sore
> And drilled in holes, the solid oak is found
> By worms voracious eaten through and through.'"

384.—In regard to the durability of different woods, the most odoriferous kinds are generally esteemed the most durable; also woods of a close and compact texture are generally more durable than those that are open and porous; but there are exceptions, as the wood of the evergreen oak is more compact than that of the common oak, but is not nearly so durable.

Sir H. Davy has observed, that, "in general, the quantity of charcoal afforded by woods offers a tolerably accurate indication of their durability; those most abundant in charcoal and earthy matter are most permanent; and those which contain the largest proportion of gaseous elements are the most destructible." "Amongst our own trees," he adds, "the chestnut and the oak are pre-eminent as to durability, and the chestnut affords rather more carbonaceous matter than the oak." But we know from experience that red or yellow fir is as durable as oak in most situations, though it produces less charcoal by the ordinary process. We have added, for the information of the reader, the following table of the quantity of charcoal afforded by 100 parts of different woods.

Table of the Quantity of Charcoal in a hundred Parts of Wood, according to different Experimentalists.

Kind of Wood.	Watson.*	Mushet.†	Proust.‡	Rumford.‡
Oak, dry	22·92	22·6	19	43
Chestnut	...	23·2		
Mahogany	20·82	25·4		
Walnut	26·04	20·6		
Elm	...	19·5	...	43·27
Beech	...	19·9		
Fir	15·62	...	...	44·18
Norway pine... ...	...	19·2		
Pine	...	...	20	
Scotch pine	...	16·4		
Ash	17·71	17·9	17	
Poplar	...	...	...	43·57
Lime	...	...	...	43·59
Birch...	...	17·4		
Sycamore	...	19·7		

In Count Rumford's experiments a longer period was allowed for the process; and in consequence, his results represent more nearly the real quantities of carbon in each kind of wood than the others. But even according to the common process it does not appear that the proportion of charcoal is a satisfactory criterion of the durability.

385.—An experiment to determine the comparative durability of different woods is related in Young's *Annals of Agriculture*, which will be more satisfactory than any speculative opinion; and it is much to be regretted that such experiments have not been oftener made.

Inch-and-half planks of trees from thirty to forty-five years' growth, after ten years' standing in the weather, were examined and found to be in the following state and condition:—

Cedar, perfectly sound.
Larch, the heart sound, but sap quite decayed.
Spruce fir, sound.
Silver fir, in decay.
Scotch fir, much decayed.
Pinaster, quite rotten.
Chestnut, perfectly sound.
Abèle, sound.
Beech, sound.
Walnut, in decay.
Sycamore, much decayed.
Birch, quite rotten.

This shows at once the kinds that are best adapted to resist the weather; but even in the same kind of wood there is much difference in the durability; and the observation is

* *Chemical Essays*, vol. iii. † *Philosophical Magazine*, vol. ii.
‡ Dr. Thomson's *System of Chemistry*, vol. iv.

as old as Pliny, that the timber of those trees which grow in moist and shady places is not so good as that which comes from a more exposed situation, nor is it so close, substantial, and durable; and Vitruvius has make similar observations.

Also split timber is more durable than sawn timber, for in splitting, the fissure follows the grain, and leaves it whole, whereas the saw divides the fibres, and moisture finds more ready access to the internal parts of the wood. Split timber is also stronger than sawn timber, because the fibres being continuous, they resist by means of their longitudinal strength; but when divided by the saw, the resistance often depends upon the lateral cohesion of the fibres, which is in some woods only one-twentieth of the direct cohesion of the same fibres. For the same reason, whole trees are stronger than specimens, unless the specimens be selected of a straight grain; but the difference in large scantlings is so small as not to be deserving of notice in practice.

Before proceeding to describe the particular woods, it will be necessary to explain the differences in their structure, and to make the reader acquainted with the means that have been adopted to ascertain their properties.

ON THE STRUCTURE AND CLASSIFICATION OF WOODS.

386.—To the experienced eye of a workman the general appearance of each variety of wood has become so familiar, and its most obvious characters are so strongly impressed on his memory, that he readily knows them one from another; but, nevertheless, the notice of some characters that are peculiar to certain kinds of woods may be of use, especially to young men, who will find both information and amusement in making collections of specimens, in examining their properties, and in rendering themselves familiar with their uses.

In a section of a tree it clearly appears that the wood is composed of separate layers, or rings, regularly disposed round the pith, which is in general nearly in the centre of the tree; but the thickness of these layers is seldom, if ever, perfectly regular.

When examined by a magnifier, the wood appears to consist of fine divisions like rays, spreading from the pith to the bark, with pores between them, often empty, but sometimes filled with some kind of vegetable matter. In the resinous woods most of the pores are filled.

Besides the fine divisions, which are often scarcely to be distinguished by the naked eye, there are, in some woods, other divisions that are larger; like the fine rays passing from the pith to the bark, they are generally of a light silvery colour, and are called the silver grain, or larger transverse septa. When a piece of wood is cut so as to pass obliquely through the larger septa or silver grain, it produces that fine flowered appearance so well known in the oak.

The fine divisions, or lesser transverse septa, are common to all woods except the palm, though in some they are not very distinct; but there are only some kinds that have the larger septa, or silver grain; therefore this forms a natural character for distinguishing the

kinds of wood. And they may be divided into two classes, one that has, and the other that has not, the larger septa or silver grain. These rays, which extend from the pith to the outer bark, are called by botanists the "Medullary rays." (See Art. 334.)

Again in some woods each annual layer or ring seems to be nearly uniform in its texture, and the line of separation between the layers is not very distinct, being so indistinct in some woods as to be "as it were shadows of circles, nothing real." Mahogany is an example of this structure; and the robinia caragna of Hill is of this kind.*

But in other woods one part of the layer is nearly compact, and the rest of it presents the appearance of a circle of empty pores; of which we have an example in the ash. This structure is remarkably distinct in Hill's section of the arbutus.*

There is a third kind, in which nearly all the pores appear to be filled with resinous or gummy matter; and one part of the layer consists of a compact, hard, and dark-coloured substance, the other part is lighter coloured and softer. All the resinous woods are of this kind.

387.—According to these distinctions, the arrangement of the following table is made:—

- WOODS.
  - CLASS I.—With larger transverse septa, or medullary rays.
    - *Division* 1.—Very distinct annual rings, one side porous, the other compact. } Oak.
    - *Division* 2.—Annual rings not very distinct, and their texture nearly uniform.
      - Beech.
      - Alder.
      - Plane.
      - Sycamore.
  - CLASS II.—No larger transverse septa, or medullary rays.
    - *Division* 1.—Annual rings very distinct, one side porous, the other compact.
      - Chestnut.
      - Ash.
      - Elm.
      - False acacia.
    - *Division* 2.—Annual rings not very distinct, and their texture nearly uniform.
      - Mahogany.
      - Walnut.
      - Teak.
      - Poona.
      - African teak.
      - Poplar.
    - *Division* 3.—Annual rings very distinct, pores filled with resinous matter; one part of the ring hard and heavy, the other soft and light coloured.
      - Cedar of Lebanon.
      - Larch.
      - Yellow fir.
      - White fir.
      - American pine.
      - Cedar.
      - Cowrie.

The only properties of wood which seem to require explanation are the cohesive force, the modulus of elasticity, permanent alteration, the stiffness, the hardness, and the toughness.

388.—The *cohesive force* or *tensile strength* of a bar or beam is equal to the power or weight that would pull it asunder in the direction of its length (see Art. 79). The weight (S) that would pull asunder a bar of an inch square of different kinds of wood has been ascertained by experiments (see Tables I., II., and XXXVIII.) Of these experiments we have taken the highest and lowest result for each kind of wood. Experiments have been

* Hill on the *Construction of Timber*.

made by Muschenbroek,* Emerson,† Rondelet,‡ Anderson, Barlow,§ Bevan, Dennison, and Laslett.‖

389.—The *modulus of elasticity* (E) is the measure of the elastic force or resistance to stretching of any substance. Dr. Thomas Young has by means of it given some very elegant demonstrations of the laws of resistance. As it is the measure of the elastic force, its use must be evident when it is considered that it is only the elastic force of timber that is employed in resisting the usual strains in carpentry; and the learned reader will readily perceive that the constant numbers employed in the rules for the stiffness of timber have for one of their elements the modulus of elasticity.

By means of the modulus of elasticity the comparative *stiffness* of bodies can be ascertained. For instance, its weight for cast-iron is 18,240,000 lbs., and its weight for oak is 1,714,500 lbs. Hence it appears that the modulus for cast-iron is 10·6 times that of oak, and therefore a piece of cast-iron is 10·6 times as stiff as a piece of oak of the same dimensions and bearing (see Tables I., II., X., XVI., and XXXVIII).

Permanent alteration of structure takes place when a certain degree of strain continues for above a certain time, and as this alteration is a partial fracture, or at least failure of the material, it is of the greatest importance that the strain should never be more than that producing such alteration, and in timber this appears to be about one-fifth of the cohesive force. (See Art. 101.)

390.—A *hard* body is that which yields least to any stroke or impressive force; and it may be shown, by the principles of mechanics, that in uniform bodies the degree of yielding is always proportional to the weight of the modulus of elasticity; therefore a table containing the weights of the modulus of elasticity of such bodies shows also their relative hardness and stiffness.

The relative hardness is determined with considerable accuracy by means of the modulus of elasticity; but the methods used for ascertaining the hardness of mineral bodies is very defective: and the method proposed by Dr. O. Gregory, in his *Treatise on Mechanics*, from the theory of percussion, is not susceptible of any tolerable degree of accuracy, from the difficulty of making correct experiments.

As the hardness follows the same laws as the stiffness, cast-iron is 10·6 times as hard as oak. But when the substance is not uniform, the hardness thus found is that of the hardest part. Thus, in fir, it is the darker part of the annual ring that is the hardest, and which determines the extent to which a beam will bend without fracture. Dry wood is harder than green; consequently it is more difficult to work. According to Belidor the labour of sawing dry oak is to that of sawing green as 4 is to 3, nearly.

391.—In respect to the *toughness* of woods, that wood is the toughest which combines the greatest degree of strength and flexibility; hence that wood which bears the greatest load, and bends the most at the time of fracture is the toughest. From the data obtained by experiments the comparative toughness of different woods has been ascertained.

392.—The opposite to hardness is softness, the opposite to toughness is brittleness, and

* *Intro. ad Phil. Nat.*, tome i.
† *Mechanics.*
‡ *L'Art de Batir*, tome iv.
§ *Treatise on the Strength of Materials.*
‖ *Timber and Timber Trees.*

the opposite to stiffness is flexibility; therefore, when the hardness, toughness, or stiffness of a wood is expressed by a low number, it may be considered to have the opposite quality.

393.—Oak in the following articles has been made the standard of comparison: its strength, toughness, and stiffness each having been assumed to be 100; and in so doing, the mean tensile strength or cohesive force of oak is taken at 11,880 lbs. per square inch, and its modulus of elasticity at 1,714,500 lbs. per square inch.

Having thus laid before the reader the means adopted for arriving at the properties of the woods, we scarcely need say that it is those properties which determine its fitness for the different purposes of carpentry. In some cases stiff woods are required, as in the joists and rafters of a building; in other cases tough wood should be employed, as for the shafts of carriages; and in other cases strength is necessary, as in ties, and other timbers strained in the direction of their length.

Tough woods, which are also hard, are the most difficult to work, especially if cross-grained; on the contrary, brittle woods work easily; and hard woods preserve the best surface.

In general, where straightness is desirable, stiff woods should be preferred; where sudden shocks are to be sustained, tough woods are the best; where little strength is required, but much labour is to be put upon it, a soft brittle wood should be preferred; and where a fine surface is to be preserved, a hard wood should be chosen; so that it is not in carpentry alone that these researches will be useful, for they are equally applicable to any art where timber is employed; and particularly in that most important application of carpentry, Naval Architecture.

DESCRIPTION OF WOODS.

CLASS I.

394.—The first class contains all woods that have larger medullary rays or transverse septa (silver grain). The woods of this class are compact, hard, and heavy; never very deep coloured, the oak being the darkest coloured of the class; they are nearly free from smell, and never resinous.

This class is formed into two divisions: one containing those woods in which the annual rings are distinctly porous on one side, and compact, or nearly compact, on the other; the other division contains those in which the annual rings are sensibly uniform, and only to be distinguished by a difference of colour.

DIVISION I.

395.—In this division we have only observed one species, the oak, which is universally allowed to be the best of woods.

1.—*Oak.*

396.—Of the oak (the *Quercus* of botanical writers) there are several species, which produce valuable timber. Vitruvius enumerates five kinds, viz.: the esculus, the cerrus, the quercus, the suber, and the robur; the timber of each being distinguished by its peculiar properties: but it would be difficult to identify some of the kinds mentioned by him with the species described by botanical writers. Vitruvius, by his observations, shows that the qualities of the different species were attended to; and they must also have been well understood by the Gothic builders in this country, for in the roofs and beams of most of their buildings we find a very superior kind of oak, which sometimes closely resembles, and is often mistaken for, chestnut. (See Art. 404.) This kind of oak is sometimes called the "Irish oak." Evelyn commends the Irish oak for resisting the worm; but to what species of oak he alludes we have not been able to determine.

At the present time the Sussex oak is esteemed the best which England affords: its superiority, according to Marshall, is chiefly to be attributed to the nature of the soil;* perhaps also in some degree to good management, for the management of woods makes a considerable difference in the value of the timber. Miller states, that he observed many large trees of the kind with long stalks to the acorns in the wolds of Kent and Sussex.† From this it would appear that the common, and consequently the valuable, Sussex oak, is not of that species; but whether it be or not we have not been able to ascertain.

In general the English oak is spoken of by practical men as though there were but one species, and no difference in the quality of the wood, except that produced by soil and situation; but three distinct species have been long known to English botanists; and it appears, from the observations and inquiries we have made, that the kinds which are common in different districts are different species.

Common British oak (*Quercus robur*) is found throughout the temperate parts of Europe, and is that which is most commonly met with in the woods and hedges of the South of England. Of this there are three district varieties, viz.: *Pedunculata; Sessiliflora; Pubescens.*

The leaves of *Quercus robur pedunculata* are irregularly sinuated, with short or scarcely any foot-stalks; the acorns have long stalks. In favourable situations this species attains an immense size. A fine healthy tree, growing (in 1820) in the grounds of Earl Cowper, at Panshanger, Herts, measured nearly 18 feet in circumference, at 5 feet from the ground; and the whole height of the tree exceeded 75 feet.

The wood of this species has often a reddish tinge; the large septa or medullary rays are always very numerous, producing large flowers; the grain is tolerably straight and fine, and it is generally free from knots; sometimes closely resembling foreign wainscot. It splits freely, and makes good laths for plasterers and slaters; and it is decidedly the best kind of oak for joists, rafters, and for any other purposes where stiff and straight-grained wood is desirable.

* *Rural Economy of the Southern Counties*, vol. ii.

† *Gardener's Dictionary*, Art. "Quercus."

The sessile-fruited oak, bay-oak of Bobart, Norwood oak of Martyn (*Quercus robur sessiliflora*), is a native of the woods and hedges of the temperate parts of Europe, and appears to have been first noticed as a distinct species in this country by Mr. Bobart, in Bagley Wood, and near Newbury, in Berkshire. It has been observed by Miller, near Dulwich, in Surrey; and it appears to be the common oak of the neighbourhood of Durham, and perhaps generally of the North of England. There are also some fine specimens to be seen in the Forest of Dean, Gloucestershire.

A few trees of this kind have been observed by Mr. Atkinson, in the grounds of Thomas Hope, Esq., near Dorking, Surrey; and there are also some very fine trees in the Earl of Mansfield's grounds at Kenwood, where the author had an opportunity of comparing the trees of the two species; but could not observe any difference in their growth or general form, except that the sessile-fruited oak had a more graceful appearance, which renders it superior as an ornamental tree.

The leaves have longish foot-stalks, often nearly an inch long, and they are more regularly and less deeply sinuated than those of the robur. The acorns sit close to the branches, having very short or scarcely any stalks.

The wood is of a darker colour than that of the pedunculata, and the larger septa or medullary rays are not so abundant; sometimes there are very few septa. The smoothness and gloss of the grain makes it resemble that of chestnut. It is heavier, harder, and more elastic than the wood of the pedunculata, and is very subject to warp and split in seasoning. It is very tough and difficult to split, therefore not fit for laths. This is most probably the reason that oak laths are so seldom used in the North of England. In respect to the comparative durability of the woods of the two species, it is a question that requires to be investigated. It appears, as far as can be determined from the structure of the wood, that the fine oak found in old Gothic roofs is of the sessile-fruited kind; at the same time it must be owned that our means of judging are not so satisfactory as to enable us to decide on this point with certainty; but we know that the old oak is very durable.

The strength, elasticity, toughness, and hardness of the sessile-fruited oak render it superior for ship-building; but it is both heavier and more difficult to work than the pedunculata; how far they may differ in durability remains to be determined. The wood for the old *Sovereign of the Seas* was from the North. Is it not probable that the greater part of it was of the sessile-fruited oak? The hardness of the timber "when taken in pieces after forty-seven years' service" is in favour of this conjecture.

In order to make experiments on the two species, when grown at the same place, and nearly of the same age, the author was supplied with specimens by Mr. Atkinson. These specimens were from trees grown in the grounds of Thomas Hope, Esq., at Deepdene, near Dorking, Surrey, which were directed to be cut by Mr. Hope for the express purpose of comparing the woods.

The trees were cut a little before the fall of the leaf, and being cut into small scantlings after drying two months they were submitted to experiment.

The following table shows the results of trials on two pieces, each piece an inch square, and sustained by supports 24 inches apart, the weight being applied in the middle of the length:—

Species of Oak.	Specific gravity.	Weight of a cubic foot in lbs.	Comparative stiffness or weight that bent the piece seven-twentieths of an inch.	Comparative strength or weight that broke the piece.
			lbs.	lbs.
Quercus robur pedunculata...	·807	50·47	167	322
Quercus robur sessiliflora ...	·879	54·97	149	350

Both these specimens broke short without splitting; therefore these experiments offer a very fair view of the properties of the two species. The sessiliflora bent considerably more at the time of fracture than the pedunculata, but it could not be measured with that correctness which is necessary to render such data useful.

The following table contains the values of the cohesive force, and modulus of elasticity calculated from the above experiments.

Species of Oak.	Cohesive force of a square inch in lbs.	Weight of modulus of elasticity in lbs. for a square inch.	Comparative toughness.
Quercus robur pedunculata ...	11,592	1,648,958	81
Quercus robur sessiliflora ...	12,600	1,471,256	108

These pieces were hastily, and therefore imperfectly, seasoned; but as they were treated exactly alike, this would not affect the comparison.

There is another species, called the Durmast oak (*Quercus robur pubescens*), which is a native of France and the South of England; its wood is not so strong nor of so firm a texture as the English oak, and it retains its foliage much later. The fruit of this variety is very nearly sessile.

The Austrian oak is a taller tree than the English oak; but the wood is whiter, softer, and less valuable.

Of the American species the chustnut-leaved oak (*Quercus prinus*) is a tall tree, remarkable for the beauty of its form: the wood is cross-grained, but is very serviceable, and is much used for wheel carriages.

The mountain red oak (*Quercus rubra*) is a native of Canada and the country west of the Alleghany Mountains: it is called the red oak, from the leaves changing to a red or purple colour before they fall off. It is a large and fine tree, of 90 or 100 feet in height, and of rapid growth; the wood is of a brown colour, and useful for the purposes of the cabinet-maker, being straight-grained and easy to work, and stands well after seasoning; but is not fit for building purposes, as it is light, spongy, and not very durable.

The white oak (*Quercus alba*), so called from the whiteness of its bark, is a native of the woods from New England to Carolina, and acquires an immense size in some of the middle States. Its wood is tough and pliable, and it is preferred to all others in America for both

house and ship carpentry, being much more durable than most other species. It is nearly as strong and durable as British oak, and is of quicker growth, but the wood is less heavy and compact. It is superior to British oak in elasticity, and can be readily bent for ship timbers. Its specific gravity is ·983.

The blunt-lobed iron oak (*Quercus obtusiloba*) is another of the American species that produces very valuable ship timber: the wood is hard, and not liable to decay, and is preferred for fencing. It is found in most of the upland forests from Canada to Florida, and is a tree of 60 or 70 feet in height.

But the live oak (*Quercus virens*) is esteemed the best of the American kinds for ship-timber; it grows to the height of 40 or 50 feet, with wide-spreading branches, and the wood is very durable; out of 507 pieces which had been in the *Essex* frigate twelve years, only six were found to be defective. It thrives best near the sea, and is found chiefly on the coast of Florida and Louisiana. The timber is yellowish or brown, heavy and compact, is good for ship-building, and more durable than the white oak. It is very strong, but crooked, and of small scantling, hard to work, tough, and twisted in the grain.

The French oak from Brittany and Normandy is found by Mr. Laslett to resemble British oak, and to be quite equal to it for the purposes of ship-building. Its specific gravity is ·976.

The Italian oak, of which there are several varieties of species, is brown, hard, tough, and strong; but less elastic and slightly heavier than British oak. It is also apt to split in seasoning, but makes strong and durable timber. According to Mr. Laslett the specific gravity of Tuscan oak is ·729, of Modena oak, ·760, of Sardinian oak, ·786.

The Turkey oak (*Quercus cerris*), which grows in Spain and the South of Europe, has an abundance of silver-grain (larger medullary rays), and is much used for ship-building.

There is another species (*Quercus sessiliflora*) found in large quantities in European Turkey.

The Evergreen oak (*Quercus ilex*) is found in the South of France and Europe. Its timber is equal to that of the British oak.

The Riga oak comes from the interior of Russia, but is not very abundant; it has a fine straight grain free from knots, and is chiefly used as wainscot for joinery and cabinet work.

The Dantzic oak is obtained from the forests of Poland, and is much used for ship-building, as its planks are pliable and elastic, so as to be easily bent when steamed. It stands well, shrinks moderately, and does not split much in seasoning. Its specific gravity is ·838.

Oak of a good quality is more durable than any other wood that attains a like size, whether driven into the earth, or kept under water, or in a dry state. The more compact it is, and the smaller the pores are, the longer it will last; but the open, porous, and foxy-coloured oak, which grows in some parts of Lincolnshire, and in some other places, is not nearly so durable, the heart of such oak being scarcely superior to the sap-wood of other kinds. It is useful for ship-building and for most of the purposes of the carpenter, particularly in situations where it is exposed to the weather. It makes the best wall-plates, ties, templets, king-posts, and indeed it is best suited for every purpose where its warping in drying and its flexibility do not render it objectionable; but it is very subject to twist, and occasionally cracks in the work it is employed in.

The colour of the oak is a fine brown, and is familar to every one. It is of different shades; that inclined to red is the most inferior kind of wood. The larger transverse septa are in general very distinct, producing beautiful flowers when cut obliquely. Where the septa are small and not very distinct the wood is much the strongest. The texture is alternately compact and porous; the compact part of the annual ring being of the darkest colour, and in irregular dots, surrounded by open pores, producing beautiful dark veins in some kinds, particularly in pollard oaks.

Oak has a peculiar smell, and the taste is slightly astringent. It contains gallic-acid, and is blackened by contact with iron when it is damp, both the iron and the wood being destroyed at the place of contact.

The young wood of English oak is very tough, often cross-grained, and difficult to work, and does not combine well with glue. Foreign wood, and that of old trees, is more brittle and workable. Oak warps and twists much in drying, and shrinks about one thirty-second part of its width in seasoning.

The cohesive force (S) of oak varies from 7,850 to 17,892 lbs. per inch. The mean of Mr. Barlow's experiments is 10,000 lbs. We have taken 11,880 as a standard to compare with the other woods, being the result of an experiment on a specimen of mean quality.

The weight of the modulus of elasticity (E) for a square inch is 1,714,500 lbs., from mean of various specimens.

Mr. Laslett* gives the cohesive strength and elasticity of a square inch of different kinds of oak as follows:—

English oak	S = 7,571 lbs. ...	E = 1,545,600
French oak	S = 8,102 „ ...	E = 2,480,880
White American oak ...	S = 7,021 „ ...	E = 2,144,600
Dantzic oak	S = 4,212 „	

Lieutenant Dennison gives the modulus of elasticity for seasoned white American oak as 1,536,000. (See Table X., Section II.)

The weight of a cubic foot of different kinds, when seasoned, is as follows:—

English oak, from	45 to 58 lbs.
Riga oak	43 „ 54 „
Red American oak	37 „ 47 „
White American oak	50 „ 56 „
Adriatic oak	58 „ 68 „

* *Timber and Timber Trees.*

Representing the strength, stiffness, and toughness of the common English oak (*Quercus robur pedunculata*) each by 100, it may be compared with the other kinds as under:—

	Common English Oak.	Riga Oak.	American Oak.	Dantzic Oak.
Strength	100	108	86	107
Stiffness	100	93	114	117
Toughness	100	125	64	99

The specimens of Riga and Dantzic oak were of the best quality.

DIVISION II.

397.—In the second division there are several species; but only four are here described, namely: beech, alder, plane, and sycamore. The woods of this division are very uniform in their texture, and very durable in water: they are useful for piles and planking in wet situations, but not applicable to other kinds of carpenter's work. Woods of this division do not warp so much as those of the first division.

1.—*Beech.*

398.—The beech tree (*Fagus sylvatica*) has but one species, the common beech, the difference in the wood proceeding from the difference of soil and situation; but owing to this difference the wood is distinguished by the names brown or black, and white beech. The beech is common in Europe, especially on a rich chalky soil; a considerable quantity is grown in the southern parts of Buckinghamshire, some fine specimens being seen at Burnham. And on the southern range of chalk hills the beeches are very fine, particularly near Walberton, in Sussex. The best beeches grow on a good soil, more dry than moist; and the wood is whiter than that of those grown in damp valleys, which loses its strength in drying and becomes brittle. The mean size of the trunk of the beech tree, according to Hassenfratz, is about 44 feet in length and 22 inches in diameter.

Beech is durable when constantly immersed in water, but damp soon destroys it. In a dry state it is more durable, but is soon injured by worms, whether it be in a damp or in a dry state. Duhamel observes that water-seasoned beech is much less subject to worms than that seasoned in the common way; and Ellis says, to preserve it from worms, it ought to be cut about a fortnight after midsummer, and planked immediately; then the planks should be put in water about ten days, and afterwards dried.

Beech is not useful in building, because it rots so soon in damp places, but it is useful for

piles in situations where it will be constantly wet, as it does not absord water readily; and it is very useful for various tools, for which its uniform texture and hardness render it superior to any other wood. It is also much used for furniture, and great quantities are brought to London in boards and planks. Before the introduction of cast-iron, much beech was used for railways for the collieries about Newcastle.

The colour of beech is a whitish brown, of different shades; the darker kind is called brown, and sometimes black beech; the lighter kind is called white beech. The texture is very uniform; the large septa are finer, and do not extend so far in the length of the wood as in oak; therefore the flowers are smaller. The annual rings are rendered visible by being a little darker on one side than the other. It is very uniformly porous, and might be easily made to imbibe some ingredient that would prevent the worms destroying it. (See Article 376.) It has no sensible taste or smell; it is not very difficult to work, and may be brought to a very smooth surface. The white kind is the harder, but the black is tougher, and Evelyn says it is more durable than the white.

The cohesive force of a square inch of beech is from 6,070 to 17,000 lbs., but about 12,000 is its mean cohesive force. The weight of its modulus of elasticity is about 1,316,000 lbs.; the weight of a cubic foot dry varies from 43 to 53 lbs.

Representing the strength of oak by	100,	that of beech will be	103
„	„ stiffness of oak by	100,	„	„	77
„	„ toughness of oak by	100,	„	„	138

Hence it appears that oak is superior in stiffness, but neither so strong nor so tough.

For the strength and elasticity of American beech, see Table X., Section II.

2.—*Alder.*

399.—The alder tree (*Betula alnus*) is a native of Europe and Asia, that grows in wet grounds and by the banks of rivers. The tree seldom exceeds 40 feet in height. The wood is extremely durable in water or wet ground, but it soon rots when exposed to the weather, or to damp; and in a dry state it is much subject to worms. Vitruvius has remarked, that in a wet state it will sustain the weight of very heavy piles of building without risk of accident; and that the whole of the buildings at Ravenna, which is situate in a marsh, were founded upon piles of this wood. Evelyn says, he found they used it under the Rialto at Venice, which was built in 1591. On account of the durability of alder in water, it is esteemed valuable for piles, planking, sluices, pumps, and, in general, for any purpose where it is constantly wet. And for such purposes it has been much cultivated in Holland and Flanders. It is also used for turners' wares and other light purposes. According to Britton it was used by our ancestors for scaffolding.

The colour of alder is a reddish yellow, of different shades, and nearly uniform. The texture is very uniform, with large septa or medullary rays of the same colour as the wood, therefore not very distinct, nor producing sessile flowers. It is soft, and works very easily; would cut well in carving, and make very good models for casting from. The

cohesive force of a square inch of alder varies from 5,000 to 13,900 lbs.: its modulus of elasticity is 1,086,750 lbs. for a square inch; and a cubic foot weighs from 44 to 50 lbs. in a dry state.

Representing the strength of oak by	100,	that of alder will be		80
,, ,, stiffness of oak by	100,	,,	,,	63
,, ,, toughness of oak by	100,	,,	,,	101

3.—*Plane Tree.*

400.—The plane tree has several species; the most common are the oriental plane and the occidental plane.

The oriental plane (*Platanus orientalis*) is a native of the Levant and other Eastern countries, and is considered one of the finest of trees. It attains about 60 feet in height, and has been known to exceed 8 feet in diameter. Its wood is much like beech, but more figured, and is used for furniture and things of a like nature. The Persians employ it for their furniture, doors, and windows.

The occidental plane (*Platanus occidentalis*) is a native of North America, and is perhaps one of the largest of the American trees; on the fertile banks of the Ohio and Mississippi some of the trees exceed 12 feet in diameter. It is sometimes called water-beech, button-wood, and sycamore; but the wood called sycamore in this country is a species of maple. (See Art. 401.) The wood of the occidental plane is harder than that of the oriental kind, but the occidental is the most common in Britain, and to it only the rest of this article applies.

The colour of the wood of the plane tree is nearly the same as that of beech, and it also closely resembles it in structure; it differs in the larger septa or medullary rays, as in the plane the septa are more numerous, producing very beautiful flowers when properly cut. It works easily, and stands very well.

The cohesive force of a square inch is about 11,000 lbs.; its modulus of elasticity is 1,343,000 lbs. per square inch; and it weighs from 40 to 46 lbs. per cubic foot when dry.

Representing the strength of oak by	100,	that of plane tree will be		92
,, ,, stiffness of oak by	100,	,,	,,	78
,, ,, toughness of oak by	100,	,,	,,	108

The wood of the occidental plane is very durable in water, and on that account the Americans use it for wooden quays in preference to any other kind.

Large numbers of occidental plane trees are to be seen in the London squares, where it flourishes better than any other tree, and grows very rapidly.

4.—*Sycamore.*

401.—The sycamore, or great maple (*Acer pseudoplatanus*), generally called the plane tree in the North of England, is a native of the mountains of Germany, and is very common

in Britain. It is a large tree, of quick growth, and thrives well near the sea. According to Hassenfratz the mean size of its trunk is about 32 feet in length, and 29 inches in diameter. Evelyn says that in Germany they have a better variety than the one which grows in Britain. The wood is durable in a dry state, when it can be protected from worms; but it is equally as subject to be destroyed by them as beech. It is used chiefly for furniture, and the white wood of this tree is valuable for many ornamental articles.

The colour of sycamore is generally of a brownish white; sometimes of a yellowish white, or nearly white in young wood, with a silky lustre. Its texture is nearly uniform, and the annual rings not very distinct. Its larger septa, or medullary rays, are small and close, and perhaps it might be more correctly described as having distinct smaller septa, and no larger septa. Its flowers are small, presenting a minute dappled appearance. The wood is sometimes beautifully curled. In large trees the wood is generally tainted and brittle. It is in general easy to work, being less hard than beech. The cohesive force of a square inch varies from 5,000 to 10,000 lbs.; its modulus of elasticity is 1,036,000 lbs. for a square inch. A cubic foot of sycamore weighs from 34 to 42 lbs. when dry.

Representing the strength of oak by	100,	that of sycamore is	81
,,	,, stiffness of oak by	100,	,,	,,	59
,,	,, toughness of oak by	100,	,,	,,	111

CLASS II.

402.—The second class contains all woods that have no larger transverse septa or medullary rays. To this class many woods belong, and of various colours and qualities. There are three divisions: the first and second formed on the same distinctions as the first and second in the first class (See Art. 394); the third division includes all the woods of which the pores are filled with resinous matter.

DIVISION I.

403.—In the first division of the second class the annual ring is nearly compact towards one side, and porous towards the other; and from this inequality the wood is very subject to warp in drying. Four varieties only are here described belonging to this division; these are the chestnut, the ash, the elm, and the false acacia.

1.—*Chestnut.*

404.—The chestnut (*Fagus castanea*) is commonly called the *sweet* or *Spanish* chestnut. This tree is a native of the warmer mountainous parts of Europe, and was once very common in this country; indeed it appears to have been one of the chief timbers used in earlier times. Fitz-Stephens, in a description of London in Henry II.'s time, states that a

noble forest of chestnuts grew on the north part of it; and many of the old buildings appear to have been built of this wood.

It is one of the largest and most long-lived of European trees, sometimes enduring more than a thousand years. The mean size of its trunk, according to Hassenfratz, is about 44 feet in length and 37 inches in diameter; and it is of a rapid growth. The chestnut contains only a very small proportion of sap-wood, and therefore the wood of young trees is found to be superior even to oak in durability. Marshall states, in his *Rural Economy of the Southern Counties*, that hop-poles of this wood last longer than any other; and in pales, stakes, and posts, it has been known to last from twenty to thirty years, which is longer than most woods last in such situations. Mr. Kent has observed a post of chestnut taken up sound after having stood above forty years; and Miller says it will endure longer than elm to convey water underground. It has been supposed that many of the old Gothic roofs, as that of Westminster Hall, were constructed of chestnut, but upon careful examination they have been generally found to be of oak. (See a paper read at the Royal Institute of British Architects in June, 1858, by Mr. Wyatt Papworth, "On the Assumed Use of Chestnut Timber in the Carpentry of Old Buildings.") Rondelet also observes, that several old buildings near Paris, of which the timbers were supposed to be chestnut, were examined by Buffon and D'Aubenton, who found it to be a variety of oak.

Chestnut is useful for the same purposes as oak, when the timber is not from old trees; but the wood of old trees is unfit for any situation where an uncertain load is to be borne, as it is brittle, and, as Evelyn states, often makes a fair show outwardly when it is decayed and rotten within. According to Belidor it soon rots when built in a wall, and therefore the ends of joists of this wood should have a free space left round them. Being durable under water it may be used for piles, &c.

According to Pursh, the American chestnut does not differ much from the European; it grows to a large size, is very durable, and much esteemed for fence work.

The wood of the chestnut is nearly of the same colour as that of the oak. In old wood the sap-wood of chestnut is whiter, and the heart-wood browner; but it is so much like oak that in old buildings they have been sometimes mistaken the one for the other. Sir H. Davy says, in his *Agricultural Chemistry*, "they may be easily known by this circumstance, that the pores in the alburnum of the oak are much larger, and more thickly set, and are easily distinguished: whilst the pores in the chestnut require glasses to be seen distinctly." Chestnut has no large transverse septa, or medullary rays, which is a more decided distinction, and renders it easy to know it from oak, whether the wood be old or not.

The wood is hard and compact; young wood is tough and flexible, old wood is brittle, and often shaky. It does not shrink and swell so much as other woods, and is easier to work than British oak.

The cohesive force of a square inch of chestnut varies from 9,570 to 12,000 lbs. when dry. The weight of a cubic foot dry is from 43 to 54·8 lbs.

The properties as determined from a piece of young wood in a green state are as under. The cohesive force of a square inch of green chestnut is 8,100 lbs.; the weight of the modulus of elasticity per square inch of ditto is 924,750 lbs.; the weight of a cubic foot of ditto, 54·68 lbs.

Representing the strength of dry oak by	100,	that of green chestnut is	68
„ „ stiffness of dry oak by	100,	„	„	„	54
„ „ toughness of dry oak by	100,	„	„	„	85

The following experiments were made on pieces of dry chestnut 1 inch square; the wood of the specimens submitted to experiment being taken from a tree of about thirty years' growth, and 11 inches diameter; consequently it had been rapidly grown. Its specific gravity was 0·535.

The first trial was made with the supports 30 inches apart; but a small knot near the middle caused the specimen to break with a long splinter, consequently it was not a fair measure of its strength. The fracture took place so suddenly, and so unexpectedly, that the experimenter narrowly escaped an accident; as, unlike other woods, it gave no warning whatever. The second trial was made with the supports 24 inches apart, and may be considered a fair measure of the strength of chestnut: but though the bending was very considerable, the last measure taken being 2½ inches, it broke as suddenly as the first specimen, and without any previous cracking or other signs of fracture. The result of these trials may be seen in the following table.

	Length.	Area of Section.	
First specimen	30 inches	1 inch square.	bent 0·5 inch with 85 lbs.
„ „	„	„	broke at a knot ... 153 „
Second specimen	24 inches	„	bent 0·5 inch ... 163 „
„ „	„	„	broke ... ... 296 „

According to the experiment on the second specimen, the cohesion of a square inch of Spanish chestnut is 10,656 lbs.; and the modulus of elasticity for a square inch, according to the first experiment, is 1,147,500 lbs.; according to the second experiment, 1,126,656 lbs.

It bends more than oak at the time of fracture, and therefore is tougher. Its toughness seems to permit it to yield insensibly till every particle exerts its utmost force, and then it gives way at once, more in the manner of metals than in that of woods. Its properties are compared with those of oak in the Table XXXVIII., at the end of the volume.

2.—*Ash.*

405.—The common ash (the *Fraxinus excelsior* of botanists) is a native of Europe and the North of Asia, and is the most valuable of the genus. There are other species found in North America, the strength of which is given in Table X., Section II.

The ash is a very rapid growing tree, and like the chestnut, the young wood is much more valuable than that of old trees. No timber differs more from a difference of soil and situation than the ash. The mean size of the trunk is, according to Hassenfratz,

38 feet in length and 23 inches in diameter; but sometimes this tree attains an immense size.

Ash soon rots when exposed to either damp or alternate dryness and moisture; but is tolerably durable in a dry situation. Evelyn says the best season for felling ash is from November to February, and that when felled in full sap it is very subject to the worm. The pores of ash cut in the spring are of a reddish colour, and such wood is much benefited by water-seasoning. There is no sap-wood in ash, and it is found to be durable if felled in winter and well seasoned; but otherwise is very perishable.

Ash is superior to any other British timber for its toughness and elasticity: and in consequence of these properties, it is useful wherever sudden shocks are to be sustained; as in various parts of machines, wheel carriages, implements of husbandry, ship blocks, tools, and the like; being equally as useful in the arts of war as in those of peace, in ancient as well as modern times:

> "From Pelion's cloudy top, an ash entire
> Old Chiron fell'd, and shaped it for his sire."—POPE'S HOMER.

It is too flexible for the timbers of buildings, and not sufficiently durable.

The colour of the wood of old trees is oak brown, with a more veined appearance, the veins darker than in oak; sometimes the wood is very beautifully figured. The wood of young trees is brownish white with a shade of green.

Its texture is alternately compact and porous, the compact side of the annual ring being the darker coloured, which renders the annual rings very distinct. It has no larger septa, or medullary rays, and consequently it has no flowers.

It has neither taste nor smell, and is difficult to work, except the wood of old trees, which is of a more brittle nature.

The cohesive fore of a square inch varies according to different experimenters, from 3,780 to 17,000 lbs.; and the weight of its modulus of elasticity is about 1,525,500 lbs. per square inch. The weight of a cubic foot dry varies from 34 to 52 pounds; when the weight of a cubic foot is lower than 45 lbs., the wood is that of an old tree, and will be found deficient both in strength and toughness.

Representing the strength of oak by	100,	that of ash is	119
,, ,, stiffness of oak by	100,	,, ,,	89
,, ,, toughness of oak by	100,	,, ,,	160

It exceeds oak both in strength and toughness, and in young wood the difference is still more considerable. The wood of the American ash trees appears to have less strength than that of the English trees.

3.—*Elm.*

406.—Of the elm tree (the *Ulmus* of botanists) there are five species common in Britain, viz.: the common rough-leaved elm, the cork-barked elm, the broad-leaved elm or wych hazel, the smooth-leaved or wych elm, and the Dutch elm.

The common rough-leaved elm (*Ulmus campestris*) is common in scattered woods and hedges in the southern parts of England; it is harder and more durable wood than the other species; it resists moisture well, and is therefore preferred for coffins.

The cork-barked elm (*Ulmus suberosa*) is very common in Sussex; the wood is of an inferior kind, very much resembling Dutch elm.

The broad-leaved elm or wych hazel (*Ulmus montana*) appears to be the most common species throughout Europe; it is frequent in the woods and hedges of England, particularly in the northern counties. Sir J. E. Smith says, "the wood fetches about half the price of our Norfolk campestris."

The smooth-leaved or wych elm (*Ulmus glabra*) common in Herefordshire, Essex, and the north and north-east counties of England, is also common in Scotland. It grows to a large size, and is much esteemed; it is readily distinguished by its smooth, dark, lead-coloured bark, and by its leaves being nearly smooth on the upper surface. The wood is tough and flexible, and is stated to be preferred for naves of wheels.

The Dutch elm (*Ulmus major*) is a native of Holland; its wood is very inferior to the other species; indeed, Miller says it is good for nothing.

The wych elm is the largest tree, and the Dutch elm the smallest. Hassenfratz states the mean size of the trunk of the elm tree to be 44 feet in length and 32 inches in diameter. The trunk of the common rough-leaved elm is often rugged and crooked, and the tree is of slow growth. Marshall says the Vale of Gloucester produces some very fine elms, but has not described the species.

Elm has always been much esteemed for its durability in situations where it is constantly wet; and it is also said to be very durable in a perfectly dry state, but not when exposed to the weather. The piles upon which old London Bridge stood were chiefly of elm, and remained six centuries without material decay;* and several other instances of its durability in water have been noticed.

Elm is not useful for the general purposes of building, but from its durability in water it makes excellent piles and planking for wet foundations. It is also used for water-works, such as pipes, pumps, and the like, and it is much used for coffins. The naves of wheels, the shells of blocks for tackle, the keels of ships, and sometimes the gunwales are made of elm.

The colour of the heart-wood of elm is generally darker than that of oak, and of a redder brown. The sap-wood is of a yellowish or brownish white, with pores inclined to red, and is from 1½ inches to 3 inches thick, but may be used in building, since it is as durable as the other wood. Elm is in general porous and cross-grained, sometimes very coarse grained, and has no large septa or medullary rays. It has a peculiar odour. It twists and warps much in drying, and shrinks very much both in length and breadth. It is difficult to work,

* Hutton's *Tracts*, vol. i.

but is free from heart shakes and is not liable to split, and bears the driving of bolts and nails better than any other timber. The timber of the English elm is generally esteemed the best; that of the wych elm is equally as good, but the Dutch elm is very inferior. It is said to be most durable when worked up soon after being felled.

The cohesive force of a square inch of elm varies according to different experimenters, from 5,460 to 13,200 lbs.; and the weight of its modulus of elasticity for a square inch is about 1,343,000 lbs. The weight of a cubic foot dry is from 34 to 47 lb.; seasoned from 36 to 50 lbs.

Representing the mean strength of oak by	100,	that of elm is	82
,,	,,	stiffness of oak by	100,	,,	,,	78
,,	,,	toughness of oak by	100,	,,	,,	86

According to the experiments of Mr. Couch, elm shrinks one forty-fourth part of its width in seasoning.

The rock elm of Canada is obtained in logs 11 inches to 16 inches square and from 20 to 40 feet long; the colour of the wood is a whitish brown, and it is hard, tough, and flexible, with a fine, smooth, close and silky grain. It has but little sap, which must, however, be removed as it soon perishes. It is liable to star shakes, but its cohesive strength is much greater than that of the English elm.

4.—*Common Acacia.*

407.—The common acacia, or American locust tree (*Robinia pseudo-acacia* of botanists) is a native of the mountains of America from Canada to Carolina. It is a beautiful tree, attains a considerable size, and is of very quick growth. According to Hassenfratz, the mean size of its trunk is 32 feet in length and 23 inches diameter.

The wood is much valued for its durability: some of the houses built by the first settlers in New England of this wood still continue firm and sound; and in posts, stakes, and pales, it is found to be one of the most durable kinds. It is adapted for any purpose to which oak is applied: it makes excellent tree-nails for ships, and is valuable for fencing. There are several other species; but we have only specimens of the kind now described.

The colour of the wood of the acacia is of a greenish yellow, with a slight tinge of red in the pores. Its structure is alternately nearly compact and very porous, which marks distinctly the annual rings. It has no large septa, and therefore no flowers. It has no sensible taste or odour in a dry state. It will require about the same degree of labour to work it as ash does.

The cohesive force of a square inch varies from 10,000 to 13,000 lbs.; and the weight of a cubic foot seasoned is from 49 to 56 lbs. Its other properties, determined from young wood in an unseasoned state, are as follows:—

Weight of the modulus of elasticity for a square inch, 1,687,500 lbs.

Representing the mean strength of oak by	100,	that of unseasoned acacia is	95
„	„	stiffness of oak by	100,	„	„	„	98
„	„	toughness of oak by	100,	„	„	„	92

Hence in a dry state it will be superior to oak in these properties.

DIVISION II.

408.—In the second division of the second class, the wood is uniformly porous; the distinction of the rings is chiefly owing to a difference between the colours of the sides of each ring. To this uniformity of texture may be referred the superiority of the woods in this division in retaining their original form; or, in other words, it is the reason they stand so well in work. The woods of this division are very numerous, but many of them have little durability: only six are here described; these are, mahogany, walnut, teak, poona, African teak, and poplar.

1.—*Mahogany.*

409.—Mahogany is the produce of a tree called by botanists *Swietenia mahogoni.* It is a native of the West Indies, and the country round the Bay of Honduras in America.

There are two other species of Swietenia besides the mahogany tree, which are natives of the East Indies. The one, a large tree, of which the wood is of a dull red colour, and remarkably hard and heavy. The other is only a middle-sized tree, with wood of a deep yellow colour, close grain, heavy, and durable, much resembling that of the box tree; but neither of these species is in use in this country.

The mahogany tree is stated to be of very rapid growth, and makes a very fine appearance. Its trunk often exceeds 40 feet in length, and 6 feet in diameter. The Honduras mahogany is cut down at two periods in the year; that is, at Christmas and in the autumn. The trees are cut off at about 12 feet from the ground, the workmen having a stage to work upon. The trunk furnishes wood of the largest dimensions, but for ornamental purposes the branches are preferable; the grain in them being closer and the veins more variegated. Mahogany was first brought to London in the year 1724.

In a dry state mahogany is very durable, and not subject to worms. It does not last long when exposed to the weather. It is a kind of wood that would make excellent timbers for floors, roofs, &c.; but, on account of its price, its use is chiefly confined to furniture and doors for rooms; for which purposes it is the best material in use. It is sometimes used for some parts of window frames and for sashes; but from its not standing the weather well, it is not so fit for these purposes. It has also been extensively used in the framing of machinery for cotton mills, &c.

The colour of mahogany is a red-brown, of different shades, and various degrees of

brightness; sometimes yellowish-brown; often very much veined and mottled with darker shades of the same colour. The sap-wood is from $\frac{3}{4}$ inch to 1 inch thick.

The texture is uniform, and the annual rings are not very distinct. It has no large septa, or medullary rays, but the smaller septa are often very visible, with pores between them; these pores are often filled with a white substance in the Jamaica wood, but generally empty in the Honduras kind. It has neither taste nor smell, shrinks very little, and warps or twists less than any other kind of wood.

The variety called Spanish mahogany is imported from Cuba, Jamaica, Hispaniola, and some other of the West Indian Islands, and in smaller logs than the Honduras. The size of the logs is in general about from 20 to 26 inches square, and from 18 to 35 feet in length. The Spanish mahogany is close-grained, and hard, generally of a darker colour than Honduras; free from black specks, and sometimes strongly figured; and its pores appear as if chalk had been rubbed into them.

The Honduras mahogany is imported in logs of a larger size, that is, from 2 to 4 feet square, and 25 to 40 feet in length; some planks have been got 6 or 7 feet wide. The grain of the Honduras kind is generally very open, and often irregular, with black or grey spots. The veins and figures are frequently very fine and showy; the best kind is that which is most free from grey specks, and of a fine golden colour. It holds with glue better than any other wood.

The cohesive force of a square inch of Spanish mahogany varies, according to different experimenters, from 3,800 to 7,560 lbs., and of Honduras mahogany, from 3,000 to 11,475 lbs.

The weight of the modulus of elasticity of mahogany is 1,255,500 lbs. for a square inch for Spanish, and 1,593,000 for Honduras. The weight of a cubic foot of mahogany is from 35 to 53 lbs.

Representing the strength of oak by	100,	that of Spanish mahogany is	67,	of Honduras	96
„	„ stiffness of oak by	100,	„	„	73,	„	93
„	„ toughness of oak by	100,	„	„	61,	„	99

It appears, however, from the result of experiments that the Spanish mahogany from Cuba is both stronger and stiffer than the Honduras.

2.—*Walnut.*

410.—The common walnut tree (*Juglans regia*) is a native of Persia and the northern parts of China. It was formerly much propagated in England for its wood, which was much esteemed before mahogany was introduced. The wood is very beautiful, and is still much prized by people of taste, who consider its colour to be far superior to the red-brown of mahogany.

Walnut, on account of its scarcity, is scarcely ever used for the purposes of building; indeed it is of too flexible a nature for beams, though it appears to have been used for that purpose by the ancients. Pliny observes, that it has the good property of giving warning by

cracking before it breaks; hence when the baths of Antendros failed, the bathers were alarmed in time to save themselves. The wood is durable, and not liable to be destroyed by worms; and it is much used for gun-stocks, and sometimes for furniture. It has the advantage of not producing sensible chemical action on iron or steel; hence its use for gun-stocks, handles of knives, and other steel instruments; and its value for making drawers or boxes to contain instruments of polished steel.

The Italian walnut is light brown in colour, close and fine in the grain, hard, heavy, and solid. It is obtained in planks 4 to 9 inches thick, 10 to 16 inches wide, and from 5 to 12 feet in length. Walnut logs are also brought from the Black Sea, 6 to 9 feet long, and 10 to 18 inches square.

The hickory or white walnut (*Juglans alba*) is a native of North America. It is a large tree, the trunk sometimes exceeding 3 feet in diameter. The wood of young trees is extremely tough and flexible, making excellent hand-spikes.

The black Virginia walnut (*Juglans nigra*) is also a native of America, and is found from Pennsylvania to Florida. It is a large tree, and for furniture the wood is the most valuable of the walnut-tree kind. It is of a fine grain, and beautifully veined, receiving an excellent polish. It is also durable, and not affected by worms. It is imported in logs from 15 to 30 inches square, and 10 to 20 feet in length. The heart-wood of a walnut-tree is of a greyish brown, with blackish brown pores, often much veined, with darker shades of the same colour; the sap-wood is greyish white. The colours are much brightened, and the veins rendered more distinct, by oiling. Its texture is not so uniform as that of mahogany, the pores being somewhat more thickly set on one side of the annual ring. It has no large septa, or medullary rays, nor flowers. It has a slightly bitter taste when green, and a perceptible odour. It does not work so easily as mahogany, but may in general be brought to a smoother surface. It shrinks very little. The sap-wood is about $\frac{3}{4}$ inch thick.

The cohesive force of a square inch of walnut varies from 5,360 to 8,130 lbs.; its modulus of elasticity for a square inch is 837,000 lbs., in a green state; that of seasoned white American walnut is 1,152,000 lbs.; the weight of a cubic foot varies from 40 to 48 lbs., in a dry state.

Representing the strength of oak by	100,	that of common walnut is	74
„ „ stiffness of oak by	100,	„	„	49
„ „ toughness of oak by	100,	„	„	111

These properties were ascertained from a green specimen; the strength and stiffness would be greater in a dry state.

3.—*Teak Wood, or Indian Oak.*

411.—Teak wood is the produce of the *Tectona grandis* of botanists, and is a native of the mountainous parts of the Malabar and Coromandel coasts, as well as of Java, Ceylon, and other parts of the East Indies.

The teak tree is of rapid growth, and the trunk grows erect, to a vast height, with copious spreading branches.

The wood of the teak tree is by far the most useful timber in India; it is light, easily worked, and, though porous, it is strong and durable; it requires little seasoning, and shrinks very little; it affords tar of good quality, and is rather of an oily nature, therefore does not injure iron; and is the best wood in that country for ship-timber, house carpentry, or any other work where strong and durable wood is required.*

Malabar teak is esteemed superior to any other in India, and is extensively used for ship-building at Bombay. It grows in the teak forests, along the western side of the Ghaut Mountains, and the contiguous ridges, where the numerous streams afford water-carriage for the timber. There is a variety, says Dr. Roxburgh, grows on the banks of the Godovery, in Hindostan, of which the wood is beautifully veined, closer grained, and heavier than that of the common teak tree; this kind is well adapted for furniture.

The teak imported into this country comes principally from Burmah in logs from 10 to 30 inches square and 23 to 50 feet in length. It has a yellow or brownish colour, is hard, strong, clean, and straight; is easily worked, and shrinks but little in seasoning. It contains a resinous oil which resists the action of water, and also prevents any iron that is placed in contact with it from rusting, and is therefore preferred to oak for the backing of armour-plated ships. In Burmah it is usual to "girdle" the tree three years before it is felled, which has a beneficial effect on the wood.

The cohesive force of teak-wood varies according to different experimenters from 3,300 to 15,000 lbs. per square inch, the weight of its modulus of elasticity is 2,167,000 lbs. per square inch, according to Mr. Barlow's experiments, and 2,123,880 from Mr. Laslett's experiments; and the weight of a cubic foot seasoned, varies from 41 to 53 lbs.

Representing the	strength of oak by	100,	that of teak will be		109
,,	,, stiffness of oak by	100,	,,	,,	126
,,	,, toughness of oak by	100,	,,	,,	94

From which it appears, that it is much superior to oak in these properties, except in toughness; but it is to be remembered, that these proportions are drawn from two or three experiments on teak, and most probably these were tried on very select specimens; whereas those for oak are from a mean specimen, selected from pieces of oak of various qualities. From the experiments of Mr. Laslett it would appear that the *strength* of teak is only half that of English oak.

4.—*Poona, Poon, or Peon.*

412.—The wood called poona is brought from the East Indies. It very nearly resembles a dull-coloured and greyish specimen of mahogany, and would be useful for any purpose to which such kind of mahogany is applicable; besides having a greater degree of strength and stiffness compared with its weight. Poona is used for the decks, masts, and yards of ships, and it appears to be well adapted for these purposes both by its strength and lightness. In

* Dr. Wollaston found that teak wood contains a considerable quantity of silica; Mr. Sivright also obtained similar results.—*Edin. Phil. Journal*, vol. iii.

respect to durability, we have not been able to collect satisfactory information; its texture is porous, but uniform; and the mean weight of a cubic foot in the dry state is 40·5 lbs., taken from our specimens.

The cohesive force of poona is from 10,000 to 14,700 lbs. per square inch; the mean weight of the modulus of elasticity for a base of an inch square is 1,689,800 lbs.

The specific gravity, and the relative strength, stiffness, and resilient power compared with Riga fir, as 1,000, from Mr. Barlow and Mr. Fincham's experiments, are as under:—

Specific Gravity.	Strength.	Stiffness.	Resilience.	
·579	1380	1270	1400	Barlow.
.647	1226	1230	1146	Fincham.
·613	1303	1250	1273	Mean of both.

Whence it appears that Poona is superior to Riga fir in the properties required for most wood.

5.—*Turtosa, or African Oak.*

413.—The African oak, or teak (*Swietenia senegalensis*) is imported in considerable quantities from Sierra Leone; it appears to be a kind of link between the oak of Europe and the teak of India.

It is used for the same purposes as oak, and has been extensively employed for ship-building in the navy.

The colour of the wood is a dark red or brown. The texture is uniform, the annual rings not distinct; but the smaller septa, or medullary rays, are strong and numerous. It is dense, hard, strong, and difficult to work. Its grain is fine, close, and straight, and there is no heart-shake. It shrinks but little in seasoning, and does not warp. It will stand exposure to weather for a long time without opening with surface shakes. Its crushing strength is from 4 to 5 tons per square inch.

According to experiments made in 1821, the cohesive force of a square inch of turtosa is 17,200 lbs., but Mr. Laslett's experiments make it but 7,050 lbs.; the weight of a cubic foot dry is 59·4 lbs.; but it is variable from 58 to 61 lbs. The weight of the modulus of elasticity is 1,728,000 lbs. for a square inch.

A bar 1 foot long, and 1 inch square, supported at the ends, breaks with 954 lbs. applied in the middle; and bends $\frac{1}{480}$ of its length, or $\frac{1}{40}$ of an inch by a weight of 100 lbs.

The following table gives the results of experiments by Colonel Sir F. Smith, of the Royal Engineers: they were made on large specimens, and under a variety of conditions. The first experiments were on the transverse strength:—

Kind of Wood.	Bearing.	Breadth.	Depth.	Breaking weight.	A bar 1 foot long, 1 inch square.	
					Breaking weight.	Weight bending it $\frac{1}{10}$ of an inch.
	feet.	inches.	inches.	lbs.	lbs.	lbs.
Turtosa	$7\frac{2}{3}$	3	6	10,697	760	139
,, ...	$7\frac{2}{3}$	3	4	4,816	770	145
,, ...	$7\frac{2}{3}$	6	6	18,750$\frac{1}{2}$	660	100
,, ...	$7\frac{2}{3}$	3	6	7,272	510	111
,, heartwood	10	3	6	6,720	620	136
,, outside ...	10	3	6	7,224	670	167
,, ,, ...	10	3	6	8,064	745	126
,, ,, ...	$7\frac{2}{3}$	3	6	10,464	740	124
Means of the kind usually employed					684	131
Conta or second best	$7\frac{2}{3}$	3	6	7,000	496	121
Inferior kind ...	$7\frac{2}{3}$	3	6	7,692	540	121
,,	$7\frac{2}{3}$	3	6	7,168	507	100

Sir F. Smith's Experiments on the Resistance to Tension.

Kind of Wood.	Cylinder ·25 inch in diameter pulled asunder by	Mean absolute strength of a square inch.	Mean relative strength.
	lbs.	lbs.	
African teak ...	1,064	21,000	107
,, ,, ...	1,008		
English oak ...	1,008	19,900	100
,, ,, ...	952		
Fir	728	12,000	61
,, ...	448		

Sir F. Smith's Experiments on the Resistance to Compression, the pieces 4 feet long, and $1\frac{1}{2}$ inches square.

Kind of Wood.	Weight that broke the piece.	Mean stress in lbs. per square inch.	Mean relative strength.
	lbs.	lbs.	
African teak ...	9,194	4,130	188
,, ,, ...	9,362		
English oak ...	4,154	2,200	100
,, ,, ...	5,722		

The resistance to crushing in short specimens has been given in Article 113; but Mr. Renton having made some additional experiments on African teak, the results may be usefully inserted in this place.

No.	Length.	Area.	Split with	Crushed with	Stress per square inch.
	inches.		lbs.	lbs.	lbs.
1.	4	2 inches square.	30,080	33,920	8,480
2.					9,600
3.	4	$1\frac{7}{8}$,, ,,	30,800	34,563	
4.					
				Mean	9,320

Sir F. Smith further ascertained the comparative expense of labour, between working African teak and English oak.

	English oak.		African teak.
Sawing is as ...	1	is to	1·64
Planing ,, ...	1	,,	2·10
Making sash frames...	1	,,	1·5

Hence it will appear that it is expensive to work; nevertheless it is much employed both in London, Liverpool, and other places, for docks, ship-building, &c., but it is too heavy for house-building.

6.—*Poplar.*

414.—Of the poplar tree (the *Populus* of botanists) there are five species common in England. The common white poplar, the black poplar, the aspen or trembling poplar, the abele or great white poplar, and the Lombardy poplar.

The wood of the aspen lasts long when exposed to the weather, and most of the poplars prove very durable in a dry state; agreeable to the woodman's adage—

"Cover me well to keep me dry,
And *heart* of oak I do defy."—CRAGG.

The wood of most of the species makes very good flooring for bedrooms and places where there is not much wear, and it has the advantage of not catching fire readily; or, as

Evelyn has it, "the poplar burns untowardly, and rather moulders away than maintains any solid heat." Vitruvius has justly observed of the poplars, that they are woods sufficiently strong for light purposes, being soft, white, and easy to work, and well adapted for carving; but none of the species are fit for large timbers.

There is not much difference in the wood of these species. The colour is of a yellowish or brownish white; one side of the annual rings being a little darker than the other, which renders the growth of each year visible. They are of an uniform texture, and are without the larger septa. The Lombardy, the black, and the common white poplar are the most esteemed. The Lombardy poplar is sometimes recommended for cheese-rooms and farm-houses in general, because neither mice nor mites will attack it. The cohesive force of a square inch of common white poplar is from 4,496 to 6,641 lbs., and the others will not differ much from it; the weight of the modulus of elasticity for a square inch is, for abele 1,134,000 lbs., and for Lombardy poplar 763,000 lbs.; the weight of a cubic-foot dry is, for abele 32 lbs., for common white poplar 33 lbs., for Lombardy poplar 24 lbs., for aspen and for black poplar 26 lbs.

Representing the strength of oak by	100,	that of abele is	86,	that of Lombardy poplar is	50
„	„ stiffness of oak by	100,	„	„	66,	„	„	„	44
„	„ toughness of oak by	100,	„	„	112,	„	„	„	57

DIVISION III.

415.—In the third division of the second class the woods are distinguished by the pores containing resinous matter. Some of the most useful and the most durable kinds of wood belong to this division. The cedars and the different species of pine belong to this division.

1.—*Cedar of Libanus, or the Great Cedar.*

416.—The cedar of Libanus, or *Abies cedrus* of botanists, is a cone-bearing tree, and an evergreen; it is a native of Mount Libanus, whence it has its name. The finest cedars in the time of Vitruvius grew in Candia and Africa; and there were also some grown in Syria, but we do not know of what species.

It grows to a considerable size; the mean size of the trunk, according to Hassenfratz, is about 39 inches in diameter, and 50 feet in length. Several very fine cedars have been produced in this country. The tree which furnished the specimens on which the author's experiments were made was 34 inches in diameter; it was grown at Ditton Park, near Windsor.

The wood is said to be very durable. It is stated by Pliny, that in the Temple of Apollo, at Utica, cedar was found of nearly 1,200 years old. According to Vitruvius, the statue of Diana, in the famous Temple at Ephesus, was of cedar, as well as the timber-work of the floor and ceiling of that edifice; and he further states, that the timber-work of the most celebrated

temples of antiquity was in general executed in cedar, on account of its extreme durability. The cedar used for statues was most probably the *oxycedrus* (see Art. 428); but though Vitruvius describes the cedar as having a leaf like cypress, that used for beams, floors, and other parts of the temples was most likely to be the great cedar, as it does not appear that the other kinds are large enough for such purposes. Cedar of Libanus was used by Solomon in the construction of the Temple at Jerusalem.

It has no perceptible larger transverse septa, or medullary rays; but when it is planed where it has been cut across the annual rings, the smaller septa present a very minute and beautifully dappled appearance. The general colour of cedar is a rich light yellowish brown; the annual rings distinct, each ring consisting of two parts, the one part harder, darker coloured, and more compact than the other.

It is a resinous wood, and has a peculiar and powerful odour, with a slightly bitter taste, and is not subject to the worm. It is straight-grained and easily worked, but readily splits.

The cohesive force of a square inch of cedar is 7,400 lbs.; the weight of its modulus of elasticity for a square inch is 486,000 lbs. according to the author's experiments; and the weight of a cubic foot seasoned is from 30·5 to 38 lbs.

Representing the strength of oak by	100,	that of cedar is	...	...	62
„ „ stiffness of oak by	100,	„	„	...	... 28
„ „ toughness of oak by	100,	„	„	...	... 137

From these proportions it appears that it exceeds the oak in toughness, but is vastly inferior in stiffness and strength.

2.—*Red or Yellow Fir.*

417.—Red or Yellow Fir is the produce of the Scotch fir tree (the *Pinus sylvestris* c botanists); it is a native of the hills of Scotland, and other northern parts of Europe, and common in Russia, Denmark, Norway, Lapland, and Sweden. The great forests of Norway and Sweden consist almost entirely of Scotch fir and spruce fir. The Scotch fir is exported from thence in logs and deals, under the name of redwood. Norway exports no trees above 18 inches diameter; consequently there is much sap-wood; but the heart-wood is both stronger and more durable than that of larger trees from other situations. Riga exports a considerable quantity under the name of masts and spars; those pieces from 18 to 25 inches diameter are called *masts*, and are usually 70 or 80 feet in length; those of less than 18 inches diameter are called *spars*. According to Mr. Coxe, the greater part of the Riga timber is grown in the district near the Dneiper. Yellow deals and planks are imported from Stockholm, Gefle, Frederickshall, Christiania, and various other ports of Norway, Sweden, Prussia, and Russia.

The Scotch fir is often grown in English plantations, but the wood is seldom of much value, as it succeeds only upon dry gravelly ground; and it appears to be an inferior variety of the *Pinus sylvestris* that is usually planted, if not a different species from that which produces the Riga timber. In the mountainous tract which the river Dee traverses,

in Aberdeenshire, there is a fine forest of natural grown wood; some of the trees exceed 3 feet in diameter and 90 feet in height. The wood is of a very good quality, but not equal to the best foreign kinds.

Tar, pitch, and turpentine are obtained from the Scotch fir; and the tree is not injured by extracting these products, when it has acquired a certain age; indeed some suppose the wood to be improved by it.

It is the most durable of the pine species; and it was the opinion of the celebrated Mr. Brindley, the constructor of the Grand Trunk Canal, and an opinion founded on observation, "that red Riga deal, or pine wood, would endure as long as oak in all situations."* Similar observations have been made by Mr. Semple.†

An instance of the durability of fir is given by Duhamel, who states that the piles of the foundations of an old church which had existed many centuries were found to be perfectly sound in the centre, which still had the colour and odour of resin, but the outside was a little decayed. And an instance of the durability of natural grown Scotch fir is given by Dr. Smith, who states, "that he had seen some of it, which, after it had been 300 years in the roof of an old castle, was as fresh and full of sap as new imported from Memel;" and "that part of it was actually wrought up into new furniture."‡ And here it may be observed, that foreign timber has an advantage that is too seldom allowed to that which is home-grown; for it is always seasoned in some degree before it arrives in this country, therefore cannot be employed in so unseasoned a state as British timber is generally employed.

Dantzic fir, or redwood, has a whitish colour tinged with red; it has an even and straight grain, is tough, elastic, and easily worked. It has a large amount of sap which it is difficult to distinguish in fresh logs, but is very conspicuous after exposure, being lighter in colour than the wood. It is imported in logs 18 to 45 feet long, and 11 to 20 inches square; and in deals 2 to 5 inches thick, and 18 to 50 feet long. Riga fir is similar but somewhat inferior, to Dantzic, and is rather lighter both in weight and in colour. Swedish fir is liable to shakes, but has very little sap and is much used for building; it is imported in logs 20 to 35 feet long, and 10 to 16 inches square; and in deals 3 inches thick, 7 to 9 inches wide, and 12 feet long and upwards.

The lightness and stiffness of fir render it superior to any other material for beams, girders, joists, rafters, and framing in general. It is also much used for masts and other parts of vessels. For joiners' work it is also much used, both for external and internal work, as it is more easily wrought, stands better, is nearly if not quite as durable, and is much cheaper than oak.

The colour of the wood of the different varieties of Scotch fir differs considerably; it is generally of a reddish yellow, or a honey-yellow, of various degrees of brightness. It consists in the section of alternate hard and soft circles; the one part of each annual ring being soft and light coloured, the other being harder and dark coloured. It has no larger transverse septa, and it has a strong resinous odour and taste. It works easily when it does not abound in resin; and the foreign wood shrinks about one-thirtieth part of its width in seasoning from the log.

In the best timber the annual rings are thin, not exceeding $\frac{1}{10}$ inch in thickness;

* Darwin's *Phytologia.* † *Treatise on Building in Water.* ‡ Pontey, *Forest Pruner.*

the dark parts of the rings of a bright and reddish colour; the wood hard and dry to the feel, neither leaving a woolly surface after the saw, nor filling its teeth with resin. The best Norway is the finest of this kind, and the best Riga is of similar quality, and much used for masts. Memel is stiffer, and in other respects not much inferior.

The inferior kinds have thick annual rings: in some kinds the dark parts of the rings are of a honey-yellow, the wood heavy, and filled with soft resinous matter, feels clammy, and chokes the saw. Timber of this kind is not durable, nor fit for bearing strains. Mar Forest timber is often of this kind. In other inferior kinds the wood is spongy, contains less resinous matter, and presents a woolly surface after the saw. Swedish timber is often of this kind, and is then inferior in strength and stiffness.

The cohesive force of a square inch of foreign timber varies from 7,000 to 14,000 lbs.
" " " Mar Forest " " 7,000 " 10,000 "
" " " English growth " " 5,000 " 7,000 "

The weight of a cubic foot of foreign fir, seasoned, varies from 29 to 40 lbs.
" " " English growth, seasoned " " 28 " 33 "
" " " Mar Forest, " " " 38 lbs.

The mean weight of the modulus of elasticity for a square inch
of the foreign varieties of Scotch fir of a good quality is ... 1,687,000 lbs.
of Mar Forest ... ... 845,000 "
of English ... ... 951,000 "

The mean strength, stiffness, and toughness of oak being each represented by 100, those of the different varieties of Scotch fir will be represented by the numbers below :—

Strength of foreign timber 80, of Mar Forest ditto 61, of English grown ditto 60
Stiffness " " 114, " " " 49, " " " 55
Toughness " " 56, " " " 76, " " " 65

The wood of the Scotch fir from cold climates appears to be always much harder than that which is the product of warmer countries; for from the under side of crooked pine trees the Laplanders procure what they term *kior*, which is almost as hard as box-wood; this they use for the bottoms of their sledges and for the outer part of their bows. The Norway timber is also harder than that of Riga, &c.

3.—*White Fir or Deal.*

418.—White fir is the produce of different species of spruce fir; that from the north of Europe is produced by the Norway spruce (*Abies excelsa*); but that from America is produced either by the white spruce (*Abies alba*) or black spruce (*Abies nigra*). White fir is imported in deals or planks.

The Norway spruce (*Abies excelsa*) is a native of mountains in various parts of Europe and the north of Asia. The forests of Norway afford it abundantly. A considerable quantity is imported from Christiania in deals and planks, which are esteemed the best white deals of any; not so much, Von Buch says, from the superior quality of the tree, as the regular thickness of the deals. The trees are usually cut into three lengths, generally of about 12 feet each, and are afterwards cut into deals or planks by saw-mills, each length yielding three deals or planks. A tree requires seventy or eighty years' growth before it arrives at perfection. White deals are also imported from Frederickstadt, Drontheim, and other ports in Norway; and from Gottenburg, Riga, and other of the Baltic ports. At Christiania, Mr. Coxe states that each saw-mill is restricted from cutting more than a certain quantity of deals: at that port there are 136 saw-mills, and the quantity permitted to be cut amounts to 20,000,000 standard deals, 12 feet long, and $1\frac{1}{4}$ inches thick.

It is from the Norway spruce that the Burgundy pitch is obtained. It thrives very well in some parts of Britain, and produces very good timber, little inferior to the foreign; it is somewhat softer, and the knots are extremely hard, which renders it difficult to work. White deal is very durable in a dry state, and is much used for internal joiners' work, and for furniture. It unites well with glue.

The American white spruce fir (*Abies alba*), in Canada called *epinette*, or rather *sapinette blanche*, is a native of high mountainous tracts in the colder parts of North America. The wood is not so resinous as that of the Norway spruce, and it is tougher, less heavy, and generally more liable to twist in drying. It is imported in deals and planks.

The American black spruce fir (*Abies nigra*) is a native of the high mountainous tracts from the northern parts of Canada to Carolina. The black and white spruce are so named from the colour of the bark, the wood of both kinds being of the same colour. The black spruce is said to produce the best wood; and, according to Pursh, grows to the highest trees.

The colour of spruce fir, or white deal, is yellowish or brownish white; the hard part of the annual ring a darker shade of the same colour; often has a silky lustre, especially in the American and British grown kinds. Each annual ring consists of two parts, the one hard, the other softer. The knots are generally very hard. The clear and straight-grained kinds are often tough, but not very difficult to work, and stand extremely well when properly seasoned, but are liable to warp; they are often used for topmasts, but are not suited for the best class of carpenters' or joiners' works.

The cohesive force of a square inch of Christiania deal	is from	8,000	to	12,000	lbs.
,, ,, ,, American white spruce	,,	8,000	,,	10,000	,,
,, ,, ,, British grown Norway spruce	is about	8,000	,,		

The modulus of elasticity is 1,500,000 lbs. for a square inch, taking the mean of the three kinds.

From Mr. Laslett's experiments the cohesive strength of Canada spruce is only 3,930 lbs., but its modulus of elasticity is double that given above.

A cubic foot of Christiania deal weighs from	28	to 32	lbs. when dry.
,, ,, American white spruce	29	,,	,,
,, ,, Norway spruce (British grown)	34	,,	,,

Representing the strength, stiffness, and hardness of oak each by 100,

	Christiana deal.	American white spruce.	British grown Norway spruce.
The strength will be ...	104	86	70
The stiffness „ ...	104	72	81
The toughness „ ...	104	102	60

The shrinkage of white deal is about one-seventieth part in becoming perfectly dry, according to the author's observations; the deals being in the state they are usually purchased at the timber-yards when first measured. What are termed dry deals will shrink about one-ninetieth part.

4. *American Pines;* 5. *Pitch Pine;* 6. *Silver Fir; and,* 7. *Pinaster.*

419.—The Weymouth pine, known in America as white pine, but in commerce as yellow pine (*Pinus strobus*), is a native of North America, and is imported in large logs, often more than 2 feet square and 30 feet in length, and in planks 3 inches thick from 9 to 24 inches wide, and from 10 to 20 feet long. It is one of the largest and most useful of the American pines, and makes excellent masts and yards of ships, for which it is in great demand, but cannot be relied on for more than ten years. The wood is light and soft, but is said to stand the weather tolerably well.

In joiners' work the wood is much used for mouldings, and other work where clean straight-grained wood is desirable; but it is not durable nor fit for large timbers, being very liable to take the dry rot. It has a peculiar odour.

The colour of the wood is a pale straw yellow, the texture is more nearly uniform than that of any other of the pine species, and the annual rings not very distinct. It stands very well when seasoned, and is a very good kind of wood for moulds for casting from, and for some kinds of furniture; but its softness renders it unfit for many purposes. Its strength, &c., are given in a table in the following page.

420.—Red pine (*Pinus resinosa*), so called from the redness of the bark, is a native of the pine forests of New England and Canada, and the wood is much used for many of the carpenter's purposes, and for ship-building, being tough, elastic, strong, and clean in grain; does not shrink, split, or warp in seasoning, but stands well and works up readily. It is imported into Britain in logs from 10 to 18 inches square and from 16 to 50 feet long. The wood of this tree is a yellowish white, and is very free from sap. It is heavier than that of the Weymouth pine, but has rather less cohesive strength.

421.—The pitch pine (*Pinus rigida*) is a native of the Southern States of North America, and is remarkable for the abundance and fragrance of its resin. It is a very heavy wood and tolerably durable: it is also brittle when very dry. It is of a redder colour than the Scotch pine, feels sticky, and is difficult to plane. It is imported in logs 11 to 18 inches square, and

from 20 to 45 feet long; also in planks 3 to 5 inches thick, 10 to 15 inches wide, and 20 to 45 feet long. It is much used in ship-building, and also for joiners' work, which is usually varnished to show the grain of the wood.

422.—The silver fir (*Pinus picea*) is a native of the mountains of Siberia, Germany, and Switzerland, and is common in British plantations. It is a large tree, and produces the Strasburg turpentine of commerce. It is supposed to attain its greatest perfection in this country in about eighty years, and the average increase during that period has often been a cubic foot of wood for each year. The girt of a tree at Woohouselee, Midlothian, was 7·4 feet, in 1759, at 4 feet from the ground, and in 1793 it girted 11·12 feet. The wood is of a good quality and much used on the Continent both for carpentry and ship-building. The harder fibres are of a yellow colour, compact, and resinous; the softer nearly white. Like the other kinds of fir, it is light and stiff, and does not bend much under a considerable load; consequently, floors constructed of it remain permanently level. It is subject to the worm. Wiebeking says it lasts longer in the air than in water, and it is therefore more fit for the upper parts of bridges than for piles and piers.

423.—The cluster pine (*Pinus pinaster*) is a native of the rocky mountainous parts of Europe, and is sometimes cultivated in British plantations. It is a larger tree than the Scotch pine, and produces both pitch and turpentine, and its wood is not of so red a colour. Wiebeking says, the wood of the pinaster is more durable in water than in air, that it is of a finer grain than either the pine or silver fir, and contains less resin than either.

Table of Properties of the preceding Species.

Kind.	Weight of of a cubic foot.	Weight of modulus of elasticity for a square inch. E.	Cohesive force of a square inch. S.	Comparative stiffness.	Comparative strength.	Comparative toughness.
	lbs.	lbs.	lbs.			
Weymouth pine ...	27¼	1,236,900 to 3,611,800	2,027 to 11,835	95	99	103
Red pine	34½	2,355,600	2,710			
Pitch pine	41	1,252,200 to 3,020,940	4,666 to 9,796	73	82	92
Silver fir	25½					
Pinaster	25½					

In the fifth, sixth, and seventh columns, the stiffness, strength, and toughness of oak are each supposed to be represented by 100.

8.—*Larch.*

424.—Of the larch tree there are three species: one European, and two American. The European larch tree (*Abies larix*) is a native of the Alps of Switzerland, Italy, Germany, and Siberia. The variety from the Italian Alps is the most esteemed, and has been introduced to a considerable extent in the plantations of Britain. The Duke of Athol has been one of

the most energetic in promoting this desirable object. It is a straight and lofty tree of rapid growth. A tree of seventy-nine years' growth was cut at Blair Athol in 1817, which contained 252 cubic feet of timber, and one of eighty years' growth at Dunkeld measured 300 cubic feet,* and a tree of fifty-four years' growth in Derbyshire contained 83¼ cubic feet.† According to Hassenfratz, the mean size of the trunk is 45 feet in length and 33 inches in diameter.

It is extremely durable in all situations, failing only where any other kind would fail: for this valuable property it has been celebrated from the time of Vitruvius, who regrets that it could not be easily transported to Rome, where such a wood would have been so valuable. It appears, however, that this was sometimes done; for we are told that Tiberius caused the Naumachiarian Bridge, constructed by Augustus, and afterwards burnt, to be rebuilt of larch planks, procured from Rhætia. Among these was a trunk 120 feet in length, which excited the admiration of all Rome.‡ The celebrated Scamozzi also extols the larch for every purpose of building; and it has not been found less valuable when grown in proper soils and situations in Britain.

In posts, and other situations where it is exposed to damp and the weather, it is found to be very durable. At Blair Athol it has been known to last from twenty to thirty-four years in such situations, particularly the knotty top-wood.

In countries where larch abounds it is often used to cover buildings, which when first done are the natural colour of the wood, but in two or three years they become covered with resin, and as black as charcoal; the resin forms a kind of impenetrable varnish which effectually resists the weather. Larch is not attacked by common worms, and does not inflame readily, although turpentine is largely obtained from it.

The larch, says Wiebeking, is preferable to the pine, the pinaster, or the fir for the construction of the arches of wooden bridges; and Mr. Coxe states that the borderers on the Lake of Geneva prefer it for building their vessels; indeed the larch is useful for every purpose of building, whether external or internal; it makes excellent ship-timber, masts, boats, posts, rails, and furniture. In some parts of Kamtschatka it arrives at a considerable size, and is there used for ships, and lasts extremely well.§ It is peculiarly adapted for flooring-boards in situations where there is much wear, and for staircases; in the latter its fine colour when rubbed with oil is much preferable to that of the black oaken staircases to be seen in some old mansions. It is well adapted for doors, shutters, and the like; and, from the beautiful colour of its wood when varnished, painting is not necessary.

The wood of the American black larch or Tamarack (*Pinus pendula*) is said to be nearly equal to that of the European larch; and that of the American red larch (*Pinus microcarpa*) is also of a very good quality; but they do not produce turpentine as the European kind.

Mr. Chapman states that the wood of the larch tree is much improved in hardness by barking the trees in the spring, and felling them late in the autumn; and as a want of stiffness is one of the most striking defects of larch for the carpenter's purposes, such as joists and beams, it would be desirable that further trials should be made; as, from the form of the tree, barking would be easily accomplished, as far as would be necessary.

The wood of the European larch is generally of a honey-yellow colour, the hard part of the annual rings of a redder cast; sometimes it is brownish white. In common with the

* *Philosophical Magazine*, vol. liii.

† Farey's *Derbyshire Reporter*, vol. ii.

‡ Beckman's *History of Inventions*, vol. ii.

§ *Langdorff's Travels*, vol. ii.

other species of pine, each annual ring consists of a hard and soft part. It generally has a silky lustre, and its colour is browner than that of the Scotch pine, and it is much tougher. It is more difficult to work than Riga or Memel timber; but the surface is better when once it is obtained. It bears driving bolts and nails better than any other kind of the the resinous woods. When it has become perfectly dry it stands well, but warps much in seasoning.

The cohesive force of a square inch is from 6,000 to 13,000 lbs.; the modulus of elasticity for a square inch is 1,363,500 lbs.; and the weight of a cubic foot of larch varies from 29 to 40 lbs. when dry.

Representing the mean strength of oak by	100,	that of larch is	103
,,	,,	stiffness of oak by	100,	,,	,,	79
,,	,,	toughness of oak by	100,	,,	,,	134

Of the larch-wood there are two very distinct kinds, differing much both in colour and quality; the one being of a redder colour, harder, of a straighter grain, and more free from knots than the other, which is of a white colour and coarse grain. The white kind is the most common.

425.—In order to try the value of larch as ship-timber, two ships were built; the one of larch from the Duke of Athol's estates, which was launched in November, 1820, and called the *Athol;* the other of Baltic fir, and called the *Nieman.* These vessels, after being on like service, were examined in December, 1827, when it was found that the *Athol* required only a very small repair; but the *Nieman* was found to be so very defective as to be proposed either to be broken up or taken to pieces.

On some specimens of larch of average quality, from the Duke of Athol's estates in Scotland, the following experiments were made.

426.—To determine the resistance to crushing, several pieces were tried in Messrs. Bramah's press by Mr. Renton; the first two pieces were 1·94 by ·94 inches, section; the others 2 inches by 1. The first piece, 6 inches long, bore 7,040 lbs. two hours without any sensible fracture, and

Crushed with	9,600	lbs. or	5,285	lbs. per square inch.
the second 6 inches long crushed with	10,880	,,	5,979	,,	,,
,, third 6 ,, ,, ,,	8,960	,,	4,480	,,	,,
,, fourth 6 ,, ,, ,,	9,600	,,	4,800	,,	,,
,, fifth 8 ,, ,, ,,	8,960	,,	4,480	,,	,,
,, sixth 9 ,, ,, ,,	8,960	,,	4,480	,,	,,
			Mean	4,917	lbs. per square inch.

The length within these limits has obviously little influence on the results; see Art. 113, where experiments on other woods are given.

427.—Out of a series of specimens of larch twelve were selected, and three of these as of mean quality; the rest as being all the distinct varieties; of the latter the resistance to

flexure only was measured, and is stated below. The pieces were 2 inches in breadth, 1 inch deep, and 3 feet between the supports, the load being applied at the middle between them.

Quality of Wood.	Mean inclination of the rings from the vertical.	Weight producing a depression of $\frac{1}{2}$ inch.
		lbs.
No. 1. Straight-grained, of the red kind, compact, with a strip of white sap-wood along the angle ...	1 in $1\frac{1}{2}$	140
No. 2. Of similar quality, but chiefly sap-wood	1 „ $2\frac{1}{2}$	118
No. 3. More close grown wood, but less heavy; had twisted much in drying	1 „ 2	80
No. 4. Red kind, straight-grained, and very rapidly grown wood; warped much longitudinally	1 „ 1	62
No. 5. A cross-grained piece from near the heart of a piece of top-wood, with many small knots	1 „ 2	88
No. 6. Ditto with more knots	1 „ 1	95
No. 7. A knotty specimen of the light-coloured kind, from the heart ...	horizontal	129
No. 8. A dull-grained specimen of the red kind, rather knotty	vertical	95
No. 9. Quick-grown specimen of the red kind, straight-grained and light	1 in 3	70
		Mean 97

The three specimens of average quality each bore 90 lbs. for about fifteen hours, without more than barely sensible permanent set. The first broke with 423 lbs., the second with 425 lbs., and the third with 355 lbs.; hence, we may in this wood assume that one-fifth of the breaking weight does not produce permanent alteration.

The properties derived from these trials are, that larch bears a stress of 2,450 lbs. per square inch without permanent alteration, and an extension of $\frac{1}{432}$ of its length: the weight of its modulus of elasticity for a base of an inch square is 1,020,000 lbs.; the weight of a cubic foot dry $34\frac{1}{4}$ lbs.; and the modulus of resilience 5·6.

But, from the fine specimen, No. 1 of the table in the preceding article, the properties are,—it bears a stress of 3,800 lbs. per square inch without permanent alteration, with an extension of $\frac{1}{432}$ of its length; the modulus of elasticity for a base of an inch square is 1,660,000 lbs.; the modulus of resilience is 8·8, and the weight of a cubic foot very nearly 36 lbs. Larch-wood of this quality is admirably adapted for masts of ships.

Larch is also imported from Russia, its cohesive strength from Mr. Laslett's experiments being 4,200 lbs., and its modulus of elasticity 2,596,520 lbs.

9.—*Cedar.*

428.—Of the cedar tree (the *Juniperus* of botanists) there are several species that produce valuable wood. There are also several other kinds of timber that are often called cedar. Thus a species of cypress is called white cedar in America; and the cedar used by the Japanese for building bridges, ships, houses, &c., is also a kind of cypress, which Thunberg describes as a beautiful wood, that lasts long without decay.

The *Juniperus oxycedrus* is a native of Spain, the South of France, and the Levant; it is usually called the brown-berried cedar. The wood of this species is supposed to have been the famous cedar of the ancients, so much celebrated for its durability, of which some of their first statues were made, before the use of marble in that branch of art was known.

The Bermudian cedar (*Juniperus bermudiana*), a native of Bermuda and the Bahama Islands, is another species that produces valuable timber for many purposes, such as internal joiners' work, furniture, and the like.

The red cedar, so well known from its being used in making black-lead pencils, is produced by the Virginian cedar (*Juniperus virginiana*), a native of North America, the West India Islands, and Japan. The tree seldom exceeds 45 feet in height.

The wood of the red cedar is very durable, and is not attacked by worms or insects. It is used for drawers, wardrobes, and various kinds of furniture, for ship-building, and for pencils. Its colour is a brownish red, the sap-wood nearly white, texture nearly uniform; it is brittle, very light, and has a strong and peculiar odour, which renders it unfit to be employed in considerable quantities for internal work.

Its specific gravity is ·650. The cohesive force of cedar, according to Muschenbroëk's experiments, is 4,875 lbs. for a square inch; but the kind is not mentioned. According to Mr. Laslett the cohesive strength of cedar from Cuba is 2,870 lbs., and its modulus of elasticity 1,798,840 lbs.

10.—*Cowrie.*

429.—The Cowrie or Cowdie pine is brought from New Zealand, and possesses many of the most esteemed qualities of the pine species; it is from a coniferous tree (the *Dammara australis*), and contains a considerable quantity of resin. It appears to shrink very little, and bears exposure to the effects of the weather very well; the mean diameter of the trunk of the tree is said to be from 3 to 6 feet, and it is from 90 to 100 feet in height, but much larger trees are frequently met with.

It is a close, even, and fine grained wood, of a very uniform texture; its colour is a light yellowish brown, the lustre silky, the annual rings marked by a line of a deeper tint of the same colour. It has a large proportion of sap-wood which is very distinctly marked. It unites well with glue, and seems admirably adapted for internal joiners' work; it is used for masts and yards of ships, for which purpose it is highly esteemed on account of its size, lightness, elasticity, strength, and durability.

The cohesive force is from 9,600 to 10,960 lbs. per square inch; the weight of the modulus of elasticity for a base an inch square is 1,982,400 lbs.; and the weight of a cubic foot dry varies from 35 to 40¼ lbs. From Mr. Laslett's experiments the cohesive strength is 4,543 lbs., and the modulus of elasticity is 2,885,600 lbs.

TABLE XXXVIII.

Properties of different Kinds of Timber.

		Kind of Wood, and state.	Specific Gravity.	Weight of the modulus of elasticity in lbs. per square inch.	Cohesive force in lbs. per square inch.	Comparative		
						Stiffness.	Strength.	Toughness.
Class I.	Div. I.	Common English oak (*Quercus robur*), dry	·750	1,714,500	11,880	100	100	100
		Riga oak, dry	·688	1,610,496	12,888	93	108	125
		Dantzic oak, seasoned	·755	1,998,000	12,780	117	107	99
		American oak	·867	1,958,700	10,253	114	86	64
	Div. II.	Beech (*Fagus sylvatica*), dry	·690	1,316,000	12,225	77	103	138
		Alder (*Betula alnus*), dry	·555	1,086,750	9,540	63	80	101
		Plane (*Platanus occidentalis*), dry ...	·648	1,343,250	10,935	78	92	108
		Sycamore (*Acer pseudo-platanus*), dry ...	·590	1,036,000	9,630	59	81	111
Class II.	Div. I.	Chesnut (*Fagus castanea*), dry	·535	1,147,500	10,656	67	89	118
		Ditto, green	·875	924,570	8,100	54	68	85
		Ash (*Fraxinus excelsior*), dry	·753	1,525,500	14,130	89	119	160
		Elm (*Ulmus campestris*), dry	·544	1,343,000	9,720	78	82	86
		Acacia (*Robinia pseudo-acacia*), green ...	·820	1,687,500	11,227	98	95	92
	Div. II.	Spanish mahogany, dry	·853	1,255,500	7,560	73	67	61
		Honduras ditto, dry	·560	1,593,000	11,475	93	96	99
		Walnut (*Juglans regia*), green	·920	837,000	8,775	49	74	111
		Teak (*Tectona grandis*)	·744	2,167,074	12,915	126	109	94
		Poona, dry	·613	1,689,800	12,350	99	104	82
		Turtosa or African Teak, dry	·954	1,728,000	17,200	101	144	138
		Poplar (*Populus dilatata*), dry	·374	763,000	5,928	44	50	57
		Abele (*Populus alba*), dry	·511	1,134,000	10,260	66	86	112
	Div. III.	Cedar of Libanus (*Abies cedrus*), dry ...	·486	486,000	7,420	28	62	106
		Riga fir (*Pinus sylvestris*), dry	·480	1,687,500	9,540	98	80	64
		Memel fir (ditto), dry	·544	1,957,750	9,540	114	80	56
		Mar Forest fir (ditto)	·684	845,056	7,323	49	61	76
		Planted Scotch fir (ditto), dry	·460	951,750	7,110	55	60	65
		Christiania white deal (*Abies excelsa*), dry	·512	1,804,000	12,346	104	104	104
		American white spruce (*Abies alba*), dry	·465	1,244,000	10,296	72	86	102
		Planted spruce (*Pinus abies*), dry ...	·555	1,393,975	8,370	81	70	60
		Weymouth pine (*Pinus strobus*), dry ...	·460	1,633,500	11,835	95	99	103
		Pitch pine...	·660	1,252,200	9,796	73	82	92
		Larch (*Abies larix*), dry	·643	1,363,500	12,240	79	103	134
		Cowrie (*Dammara australis*)	·579	1,982,400	10,960	116	92	74

In the last three columns of this table, English oak is made the standard of comparison.

TABLE XXXIX.

Specific Gravity and Weight of a Cubic Foot of different Woods.

Kind of Wood, and state.	Specific Gravity.	Weight of a cubic foot in lbs.	Kind of Wood, and state.	Specific Gravity.	Weight of a cubic foot in lbs.
Abele, dry	·511 T.	32·00	Chesnut (horse), dry ...	·596 T.	37·28
Acacia (false) green ...	·820 E.	51·25	„ „ another specimen, dry ...	·483 T.	30·18
„ dry	·791 H.	49·43	Cocoa wood	1·040 M.	65·00
„ „	·748 T.	46·75	Cork	·240 M.	15·00
„ (three-thorned) ...	·676 H.	42·25	Cowrie	·579	36·20
Alder...	·800 M.	50·00	Crab tree, meanly dry ...	·765 P.	47·81
„ dry	·555 E.	34·68	Cypress	·655 H.	40·93
Almond tree	1·102 H.	68·87	„ (Spanish)	·644 M.	40·25
Apple tree	·793 M.	49·56	Deal white. See fir.		
Apricot tree	·789 H.	49·31	„ yellow. See pine.		
Arbor vitæ (Chinese) ...	·560 H.	35·00	Ebony (American)	1·331 M.	83·18
Ash (heart-wood), dry ...	·845 P.	52·81	„ (Indian)	1·209 M.	75·56
„ dry	·832 W.	52·00	„	1·108 R.	69·25
„ young wood, dry ...	·811 T.	50·68	Elder tree	·695 M.	43·43
„	·800 J.	50·00	Elm, green	·940 C.	58·75
„	·760 B.	47·50	„	·693 S.	44·41
„ (old tree), dry	·753 T.	47·06	„ seasoned	·588 C.	36·75
„ dry	·690 E.	43·12	„	·553 B.	34·56
Bay tree	·822 M.	51·37	„ (common), dry ...	·544 E.	34·00
Beech (meanly dry)... ...	·854 P.	53·37	„ wych, young tree, green	·763 E.	47·68
„	·852 M.	53·25	„ „ „ dry	·684 T.	42·75
„	·720 H.	45·00	Filbert tree	·600 M.	37·50
„	·696 B.	43·50	Fir (Norway spruce) ...	·512 T.	32·00
„ dry	·690 E.	43·12	„ (white American spruce)	·465 T.	29·06
Birch, dry	·720 E.	45·00	„ (silver), green	·531 Wi.	33·20
Box (Dutch)	1·328 M.	83·00	„ dry	·403 Wi.	25·22
„ dry	1·030 J.	64·37	„ (Scotch). See pine.		
„	1·031 P.	64·43	Fustic	·817 R.	51·06
„ ... ... { from...	1·024 B.	64·00	Hazel...	·606 M.	37·87
„ ... ... { to ...	·960 B.	60·00	Hickory	·929 S	58·06
„ dry	·950 W.	59·37	Hornbeam	·760 H.	47·50
„ Turkey...	·949 R.	59·31	Jasamine (Spanish) ...	·770 M.	48·12
Brazil wood (red)	1·031 M.	64·43	Juniper wood	·556	34·75
Canary wood	·723 R.	45·18	Laburnum	·843 T.	52·70
Cedar (Indian)	1·315 M.	82·18	Lance-wood	1·038 L.	64·87
„ (Canadian)	·753 C.	47·06	„ „ dry	·943 R.	58·93
„ (Virginian red), dry	·650 T.	40·62	Larch, green...	·858 Wi.	53·63
„ (Palestine)	·596 M.	37·25	„ (red-wood) seasoned	·640 T.	40·00
„ (American).... ...	·560 M.	35·00	„ dry	·612 Wi.	38·31
„ „ seasoned	·453 C.	28·31	„ dry	·496 T.	31·00
Cedar of Libanus	·603 H.	37·68	„ (white wood) seasoned	·364 T.	22·75
„ „ dry ...	·486 T.	30·37	Lemon tree	·703	43·93
Cherry tree	·741 H.	46·31	Letter-wood	1·286 C.	80·37
„ „ dry	·672 T.	42·00	Lignum vitæ	1·333 M.	83·31
Chesnut (sweet), green ...	·875 E.	54·68	„	1·327 P.	82·93
„	·685 H.	42·81	Lime tree	·604 M.	37·75
„ (sweet), dry ...	·606 T.	37·95	„	·564 H.	35·25
„ another specimen, dry	·535 T.	33·45	„	·480 T.	30·00
„ (horse)	·657 H.	41·06			

Kind of Wood, and state.	Specific Gravity.	Weight of a cubic foot in lbs.	Kind of Wood, and state.	Specific Gravity.	Weight of a cubic foot in lbs.
Logwood	·913 P.	57·06	Pine (Riga), dry... from...	·480	30·00
Mahogany (Spanish), dry ...	·852 T.	53·30	Pine (Riga), dry... to ...	·466 T.	29·12
„ dry	·816 W.	51·00	„ (Weymouth), dry ...	·460 T.	28·75
„ (Honduras), dry...	·560 T.	35·00	„ (American), dry ...	·368 T.	23·00
Maple (Norway)	·795 L.	49·68	Plane (occidental) dry ...	·648 E.	40·50
„ dry	·755 P.	47·18	„ (oriental), ...	·538 H.	33·62
„ (common), dry ...	·624 T.	32·75	„ tree (common). See sycamore.		
Medlar tree	·944 M.	59·00	Plum tree	·785 M.	49·06
Mulberry tree (Spanish) ...	·897 M.	56·06	„	·663 P.	41·43
Oak (live), half seasoned ...	1·216 Ch.	76·03	Poona (seasoned)	·635 C.	39·95
„ (English), green ...	1·113 C.	69·56	Poplar (Spanish), white ...	·529 M.	33·06
„ (French), green ...	1·063 Bu.	66·43	„ (black), dry... ...	·421 T.	26·31
„ (Irish bog)	1·046 C.	65·37	„ (Lombardy), dry ...	·374 E.	24·37
„ (evergreen)	·994 H.	62·25	Quince tree	·705 M.	44·00
„ (Adriatic)	·993 B.	62·06	Sassafrass	·482 P.	30·12
„ (black bog), dry ...	·965 R.	60·31	Satin wood	·952 R.	59·50
„ (white American), half seasoned...	·908 Ch.	56·75	Saul (Bengal), seasoned ...	·994 L.	62·12
„ (*Quercus sessiliflora*), dry	·879 T.	54·97	Service tree	·742 H.	46·37
„ (American), white ...	·840 H.	52·50	Sissoo (Bengal), seasoned ...	·889 L.	55·52
„ (Provence), seasoned ...	·828 D.	51·75	Stinkwood (seasoned) ...	·681 C.	42·56
„ (*Quercus robur*), dry ...	·807 T.	50·47	Sycamore	·645 H.	40·31
„ (English), seasoned ...	·777 C.	48·56	„ dry	·590 E.	36·87
„ (Dantzic), seasoned ...	·755 T.	47·24	Teak, dry	·832 Ch.	52·00
„ (American), red ...	·752 L.	47·00	„	·745 B.	46·56
„ (Riga), dry	·688 T.	43·00	„ seasoned	·657 C.	41·06
„ (English) from an old tree, dry	·625 T.	39·06	Tulip tree	·477 H.	29·81
			Vine	1·237 M.	77·31
Olive tree	·927 M.	57·93	Walnut tree, green	·920 E.	57·50
Orange tree	·705 M.	44·06	„ (American) ...	·735 H.	45·93
Pear tree, dry	·708 T.	44·25	„ (French) ...	·671 M.	41·93
„	·646 B.	40·37	„ dry	·616 T.	38·50
Pine (American pitch), dry	·936 T.	58·5	Willow, green	·619 E.	38·68
„ (ditto), seasoned ...	·741 C.	36·31	„ dry ... ... from	·568	35·50
„ (pinaster), green ...	·837 Wi.	52·35	„ dry ... ... to...	·404 T.	25·25
„ (Scotch), green ...	·816 Wi.	51·08	Yellow wood, seasoned ...	·657 C.	41·06
„ (Mar Forest)	·696 B.	43·50	Yew (Spanish)	·807 M.	50·43
„ (planted Scotch), dry...	·529 T.	33·06	„ (Dutch)	·788 M.	49·25
„ (Scotch), dry	·429 Wi.	26·81	„	·788 H.	48·62
„ (Memel), dry from...	·553	34·56			
„ (Memel), dry to ...	·544 T.	34·00			

The letters following the specific gravities refer to the authorities:—B. Barlow; Bu. Buffon; C. Couch; Ch. from Chapman on *Preservation of Timber;* E. Ebbels; H. from Rondelet's table; J. Jurin; L. Layman; M. Muschenbroek; P. *Philosophical Transactions*, vol. i, Lowthorp's Abridgment; R. Ralph Tredgold, who collected this and the following table; S. Scoresby; T. Thos. Tredgold's Experiments; W. Watson (Bishop); and Wi. Wiebeking. See also the tables at end of Section II.

TABLE XL.

Specific Gravity and Weight of a Cubic Foot of various Substances.

Name of the substance.	Specific Gravity.	Weight of a cubic foot in lbs.
Air (atmospheric)	·0012	0·075
Alabaster. See gypsum.		
Basalt ... ... from	3·00	187·50
Basalt ... ... to ...	2·478	154·87
„ (Fairhead)	2·95 K.	184·37
„ (Derbyshire) ...	2·921 W.	182·56
„ (Giant's Causeway) ...	2·90 K.	181·25
„ „ „ ...	2·864 Br.	179·00
„ (Rowley rag) ...	2·478 K.	154·87
Beeswax (yellow)	0·965	60·31
Bismuth (cast)	9·822	613·87
Bitumen, of Judea	1·104	69·00
Brass (wire drawn)	8·544	534·00
„ (plate)	8·441 W.	527·56
„ (cast)	8·100 P.	506·25
Brick (common) ... from	1·557	97·31
Brick (common) ... to ...	2·000	125·00
„ (red)	2·168 Re.	135·50
„ (pale red)	2·085 Re.	130·31
„	1·857 Be.	116·06
„ (common London stock) ...	1·841 T.	115·06
„ paving (English clinker) ...	1·653 R.	103·31
„ (Dutch clinker) ...	1·482 R.	92·62
„ (Welsh fire)	2·408 T.	150·50
Brickwork, about	—	95·00
Cement (Roman) and sand in equal parts ...	1·817 T.	113·56
Cement, alone (cast) ...	1·600 R.	100·00
Chalk ... ... from	2·315	144·68
Chalk ... ... to ...	2·657 Th.	166·06
„ (Cambridge Clunch)	2·657 W.	166·06
„ (Dorking)	1·169 R.	116·81
Charcoal from birch ...	0·542 K.	33·87
„ „ fir	0·441 K.	27·56
„ „ oak	0·332 K.	20·75
„ „ pine	0·280 K.	17·50
Clay (potter's) ... from	1·800	112·50
Clay (potter's) ... to ...	2·085 K.	130·31
„ (common)	1·919 Be.	119·93
„ with gravel	2·560	160·00
„ slate. See slate.		
Coke	0·744 K.	46·50
Coal (Kilkenny)	1·526 K.	95·37
„ (Glasgow splint) ...	1·290 Th.	80·62
„ (Cannel)	1·272 Th.	79·50
„ (Newcastle caking) ...	1·269 Th.	79·31
Copper (British sheet) ...	8·785 Ha.	549·06
Copper (British cast) ...	8·607 Ha.	537·93
Earth (common) ... from	1·520	95·00
Earth (common) ... to ...	1·984	124·00
„ (loamy or strong) ...	2·016	126·00
„ (rammed)	1·584 Pa.	99·00
„ (loose or sandy) ...	1·520	95·00
Firestone	1·800	112·50
Flint ... ... from	2·580	161·25
Flint ... ... to ...	2·630 Th.	164·37
„ (black Cambridge) ...	2·592 W.	162·00
Freestone. See stone.		
Glass, white flint	3·000	187·50
„ plate	2·760	172·50
„ crown	2·520	157·50
Gold, pure cast	19·361 Br.	1210·06
„ standard	17·724 Th.	1107·75
Granite ... ... from	2·999	187·47
Granite ... ... to ...	2·538 K.	158·62
„ (Guernsey)	2·999 W.	187·47
„ (Aberdeen grey) ...	2·664 R.	166·5
„ (Cornish)	2·662 Re.	166·37
„ „	2·653 R.	165·81
„ (Aberdeen red) ...	2·643 R.	165·18
„ (Cornish)	2·624 T.	164·00
Gravel	1·749 P.	109·32
Gunpowder (solid)	1·745	109·06
„ (shaken) ...	0·922	57·62
Gypsum (plaster stone) ...	2·286 W.	142·87
Iron (bar) ... ... from	7·600	475·00
Iron (bar) ... ... to ...	7·800 K.	487·50
„ (hammered)	7·763 M.	485·18
„ (not hammered) ...	7·600 M.	475·00
„ (cast) ... ... from	7·600	475·00
„ (cast) ... ... to ...	7·200 Th.	450·00
„ (horizontal cast) ...	7·113 Re.	444·56
„ (vertical castings) ...	7·074 Re.	442·12
Ivory	1·826 P.	114·12
Lead (milled)	11·407 Th.	712·93
„ (cast)	11·352 Br.	709·50
„ black. See plumbago.		
Lime, quick	0·843 Be.	52·68
Limestone. See stone and marble.		
Loam. See earth.		
Marble ... ... from	2·840	177·50
Marble ... ... to ...	2·580	161·25
„ Parian white ...	2·837 K.	177·31
„ veined white ...	2·726 Re.	170·37
„ Carrara white ...	2·717 K.	169·81

Name of the substance.	Specific Gravity.	Weight of a cubic foot in lbs.
Marble, Carrara blue ...	2·713 K.	169·56
„ Italian black ...	2·712 K.	169·50
„ Derbyshire entrochal	2·709 R.	169·31
„ Saxon grey	2·700 K.	168·75
„ Brabant black ...	2·697 Re.	168·56
„ Derbyshire black ...	2·690 W.	168·12
„ Namur black ...	2·682 R.	167·62
„ Sienna yellow ...	2·677 K.	167·31
„ Pallion brown figured	2·586 R.	161·62
Marl	from 1·600 to 2·870 Th.	100·00 to 179·37
Mercury (fluid)	13·568 Br.	848·00
Mortar	1·715 Be.	107·18
Do., of river sand three parts, of lime in paste two parts	1·615 Ro.	100·93
Do., do., do., well beat together ...	1·893 Ro.	118·31
Do., of pit sand three parts, of lime in paste two parts	1·588 Ro.	99·25
Do., do., do., well beat together ...	1·903 Ro.	118·93
Do., of pounded tile, three parts, of quick-lime two parts	1·457 Ro.	91·06
Do., do., do., well beat together ...	1·663 Ro.	103·93
Do., common, of chalk-lime, and sand, dry	1·550 R.	96·87
Do., the lining of an antique reservoir near Rome ...	1·549 Ro.	96·81
Do., from the interior of an old wall, Rome	1·414 Ro.	88·37
Do., lime, sand, and hair, used for plastering, dry	1·384 R.	86·50
Oolite. See stone, roe.		
Peat, hard	1·329	83·06
Pebble (English)	2·609	163·06
Pewter	7·248	453·00
Pitch	1·150 P.	71·87
Plaster (cast)	1·286 Be.	80·37
Platina, pure.	21·531 Th.	1345·68
Plumbago, or black lead ...	2·267	141·68
Porphyry (green)	2·875	179·68
„ (red)	2·793	174·56
Potstone	from 3·000 to 2·768 K.	187·50 to 173·00
Puzzolana	from 2·570 to 2·850 K.	160·62 to 178·12
Quartz (crystallised) ...	2·655	165·93
Roe-stone. See stone.		
Road-grit. See sand.		
Sand (pure quartz)... ...	2·750	171·87
Sand, river	1·886 Be.	117·87
„ River Thames (best)...	1·638 T.	102·37
„ pit (clean but coarse)...	1·610 T.	100·62
„ pit (fine-grained and clean) ...	1·523 T.	95·18
„ scraped from London roads (road-grit)	1·494 T.	93·37
„ pit (very fine-grained)	1·480 T.	92·50
„ River Thames (inferior)	1·454 T.	90·87
Sandstone. See stone.		
Serpentine, Anglesey green	2·683 R.	167·68
„ blackish green...	2·574 K.	160·87
„ dark reddish brown	2·561 K.	160·06
Silver, pure cast	10·474 Br.	654·62
„ standard	10·312 Th.	644·50
Slate, Welsh...	2·888 K.	180·50
„ Anglesey	2·876 K.	179·75
„ Westmoreland, pale blue... ...	2·791 W.	174·43
„ Westmoreland, dark blue... ...	2·781 W.	173·81
„ Westmoreland, pale greenish blue	2·768 W.	173·00
„ Westmoreland, blackish blue, used for floors ...	2·758 W.	172·37
„ Welsh rag	2·752 K.	172·00
„ Westmoreland, fine-grained pale blue	2·732 W.	170·75
„ Cornwall, greyish blue	2·512 K.	157·00
Stone, Bath (roe-stone) ...	2·494 K.	155·87
„ „	1·975 R.	123·43
„ Blue-lias (limestone)	2·467 R.	154·18
„ Bramley-fall (sand-stone) ...	2·506 Re.	156·62
„ Bramley-fall... ...	2·261 R.	141·31
„ Bristol stone... ...	2·510	156·87
„ Burford (dry piece)	2·049 P.	128·06
„ Caen (calcareous sandstone)...	2·108 R.	131·75
„ Clitheroe limestone ...	2·686 W.	167·87
„ Collalo, white (sand-stone)	2·423 Re.	151·43
„ Collalo, white (sand-stone) ...	2·040 R.	127·50
„ Craigleith, sandstone	2·452 Re.	153·25
„ „	2·360 R.	147·50
„ Derbyshire (red friable sandstone)	2·346 Re.	146·62
„ Dundee	2·530 Re.	158·12
„ „	2·517 T.	157·31
„ (grindstone)... ...	2·143	133·93
„ Hedding-stone, lax kind ...	2·029 P.	126·81
„ Hilton (sandstone) ...	2·177 R.	136·06

Name of the substauce.	Specific Gravity.	Weigh of a cubic foot in lbs.	Name of the substance.	Specific Gravity.	Weight of a cubic foot in lbs.
Stone, Kentish rag	2·675 R.	167·18	Stone, Yorkshire paving ...	2·356 R.	147·25
,, Ketton (roe-stone) ...	2·494 K.	155·87	Stonework, mean weight according to Belidor, about	—	107·00
,, ,, ...	2·058 R.	128·62	Shingle	1·424 Pa.	89·00
,, Kincardine (sandstone) ...	2·448 T.	153·00	Steel ... ... from	7·780	486·25
,, Limerick (black compact limestone)	2·598 Re.	162·37	Steel ... ... to ...	7·840 Th.	490·00
,, Pennarth (limestone)	2·653 W.	165·81	Syenite (Mount Sorrel) ...	2·621	163·81
,, Portland (roe-stone)	2·461 W.	153·81	Tile (common plain) ...	1·853 R.	116·15
,, ,, ,, ...	2·423 Re.	151·43	,, ...	1·815 Be.	113·43
,, ,, ,, ...	2·113 R.	132·06	Tin, hammered	7·299 Br.	456·18
,, pumice	0·629 R.	39·31	,, pure cast	7·291 Br.	455·68
,, Purbeck	2·680 W.	167·50	Toadstone (Derbyshire) ...	2·921 W.	182·56
,, ,, ...	2·599 Re.	162·43	Tufa (Roman)	1·217 Ro.	76·06
,, Roach Abbey (magnesian limestone)	1·893 R.	118·31	Water, sea	1·027 Th.	64·18
			,, rain	1·000	62·50
,, Tottenhoe (calcareous sandstone)	1·800 T.	112·50	Whinstone (Scotch) ...	2·760 W.	172·50
			Wood ashes	0·933 P.	58·32
,, Woodstock flagstone	2·614 K.	163·37	Wood, petrified	2·341 P.	146·31
,, Yorkshire paving ...	2·507 Re.	156·68	Zinc	7·028 W.	439·25

Part of the letters of reference are explained in a note to the preceding table. The rest are as follows:— Be. Belidor; Br. Brisson; Ha. Hatchet; K. from Kirwan's *Mineralogy;* Re. Rennie, *Philosophical Magazine*, vol. liii; Ro. Rondelet; Th. from Dr. Thomson's *System of Chemistry*, 5th edition; and Pa. Pasley, *Course of Military Instruction.*

In bodies of a porous nature, the specific gravity, as given by the greater part of the tables the author consulted, is much above the real weight of a given bulk of the material, as compared with water. The cause of this difference is the absorption which takes place when the body to be tried is immersed in water. Let A be the weight of a body in air, W its weight in water, a the weight of water it absorbs, and S the specific gravity, then $\frac{A}{A + a - W} = S$. When the absorption is nothing, or $a = 0$; then $\frac{A}{A - W} = S$, which is the same as the common rule.

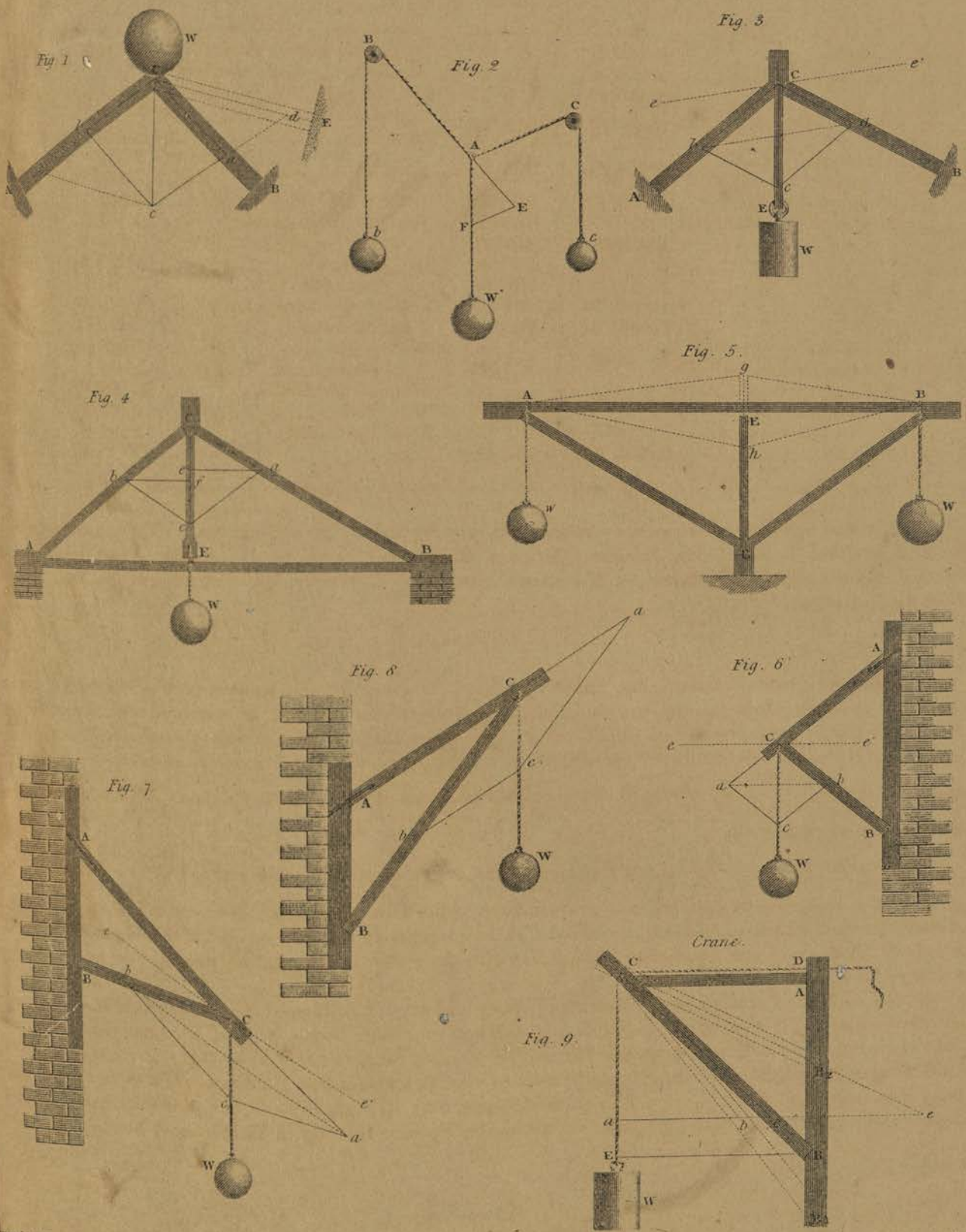
By the equation $\frac{A}{A + a - W} = S$, the specific gravities in the table marked R and T have been determined. But this method does not apply to sand and other loose materials; therefore to find the specific gravity of sand, a vessel which when filled contained a known weight of water, was filled with the sand to be tried, and weighed. The vessel used contained 1,300 grains of water; therefore, as 1,300 : weight of the sand : : 1 : specific gravity of the sand.

By the method of mixing equal volumes of water and sand, a solid specimen of quartz would be of the same specific gravity as its sand would be; but it is well known that a stone crushed into sand occupies more space than the solid stone did; and therefore the method is erroneous.

The specific weight of a cohesive earth, such as clay or loam, is best got by cutting a cubical piece, and carefully measuring and weighing it. This method is given by Kirwan, in his Essay on the *Analysis of Soils*, and is accurate enough for business. See also the article on Specific Gravity in *The Science of Building.*

Equilibrium and Pressure of Beams.

PLATE I.



Drawn by R. Predeold.

Engraved by James Davis.

Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, London, E.C.

Fig. 10

Fig. 11.

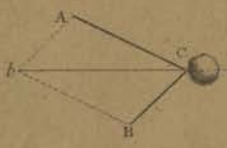


Fig. 12.

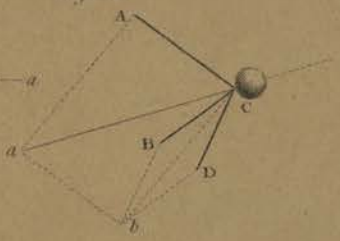


Fig. 13

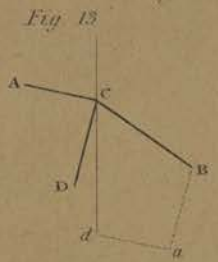


Fig. 14

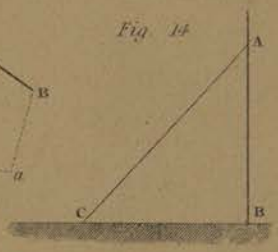


Fig. 15

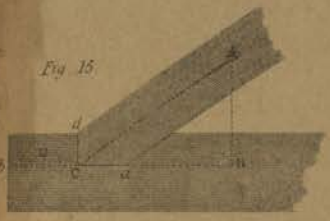


Fig. 16

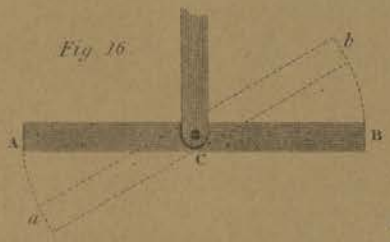


Fig. 17.

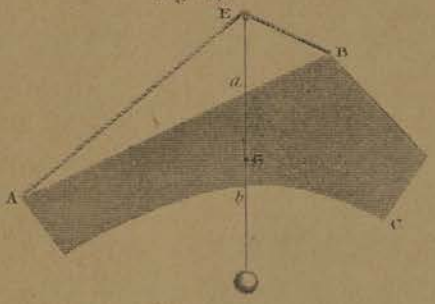


Fig. 18

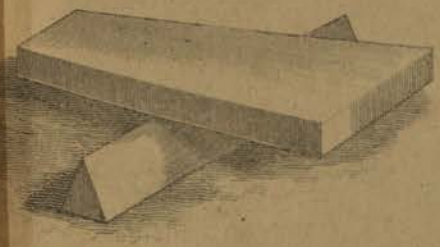


Fig. 19.

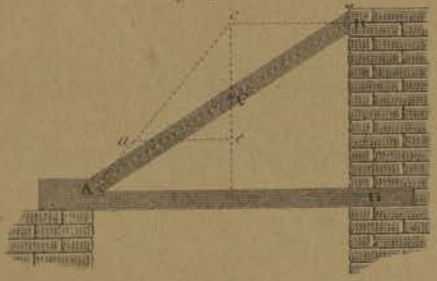


Fig. 20

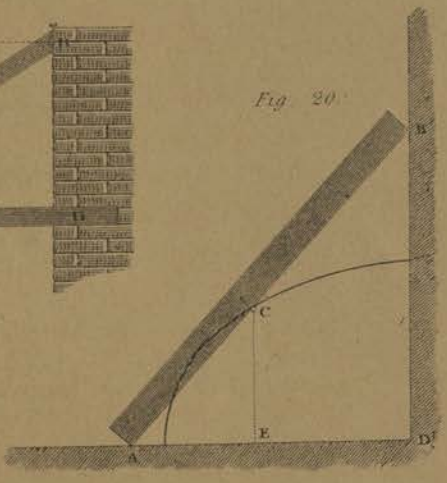


Fig. 21.

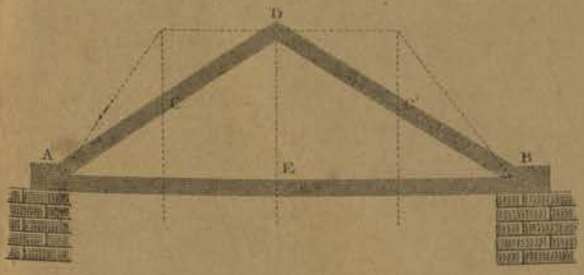


Fig. 22

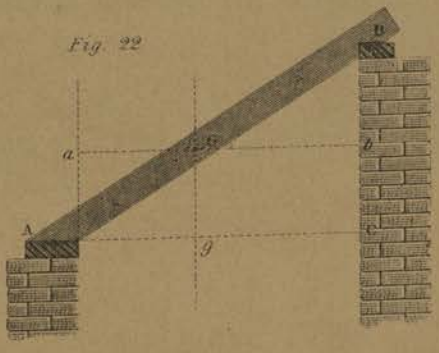


Fig. 23

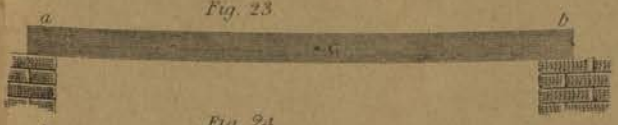


Fig. 24

by R. Dodgeld.

Engraved by James Davis.

Crosby Lockwood & Co.ª 7. Stationers' Hall Court, Ludgate Hill, London. E.C.

Equilibrium and Pressure of Beams and Framing. PLATE III.

Fig. 25.

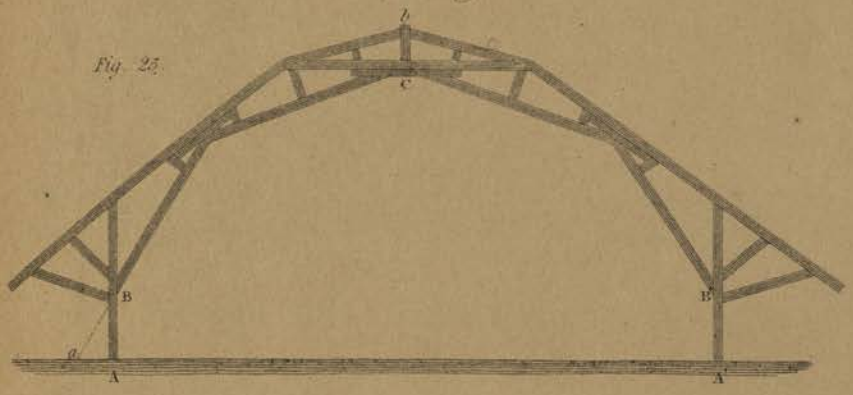


Fig. 26

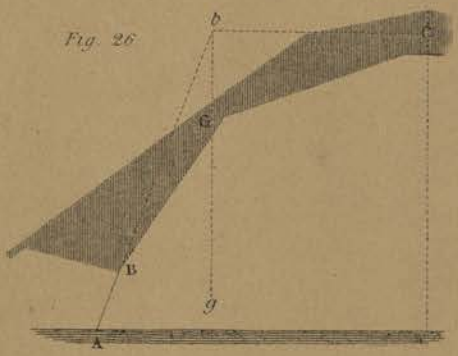


Fig. 27.

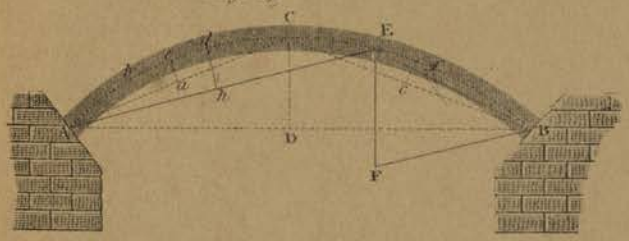


Fig. 28.

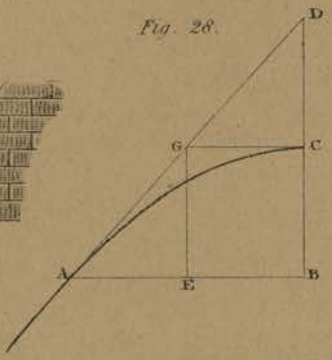


Fig. 30.

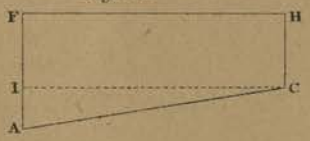


Fig. 29

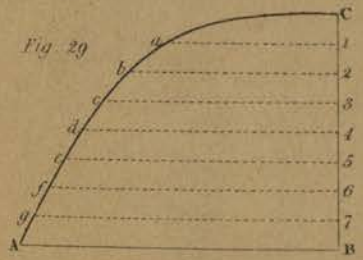


Fig. 33.

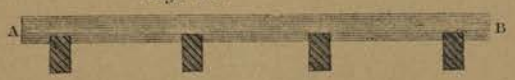


Fig 32

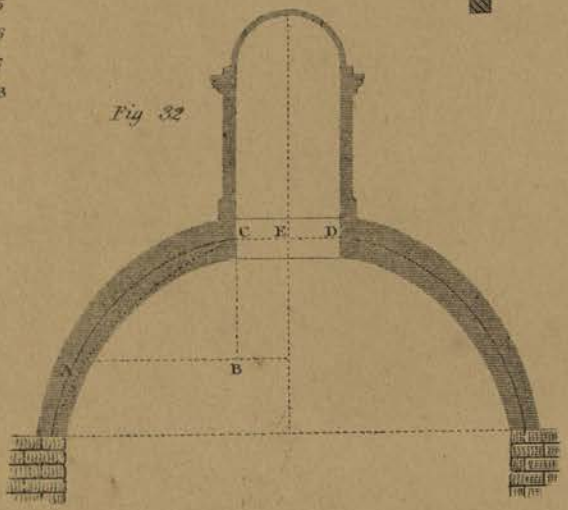


Fig. 31.

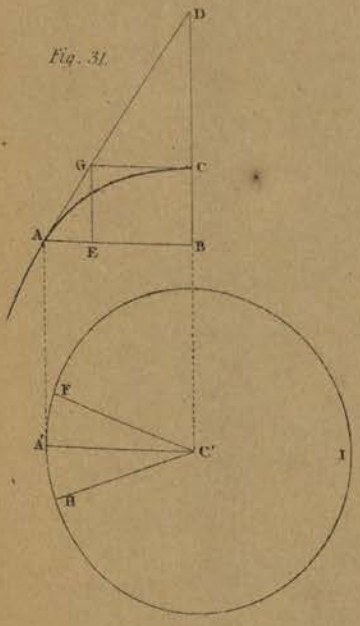


Fig. 34

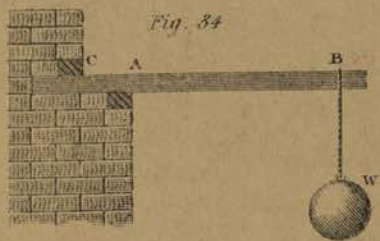
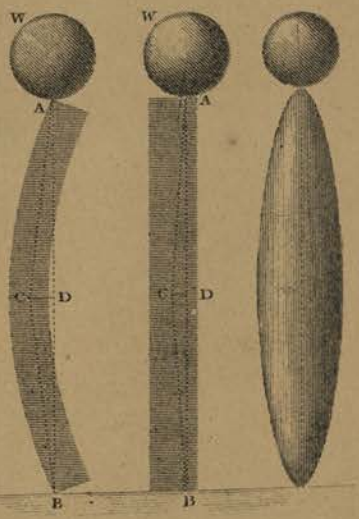


Fig. 35. Fig. 36. Fig. 37.



Drawn by R. Tredgold.

Engraved by James Davis.

Crosby Lockwood & Co's Stationers' Hall Court, Ludgate Hill, London, E.C.

Naked Flooring.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

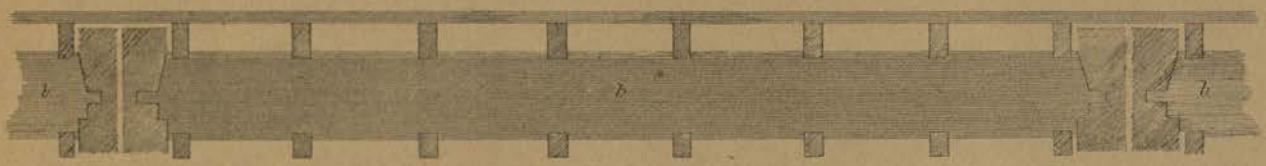


Fig. 5.

Fig. 6.

Fig. 7.

Fig. 9.

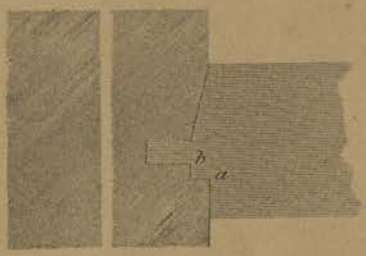


Fig. 8.

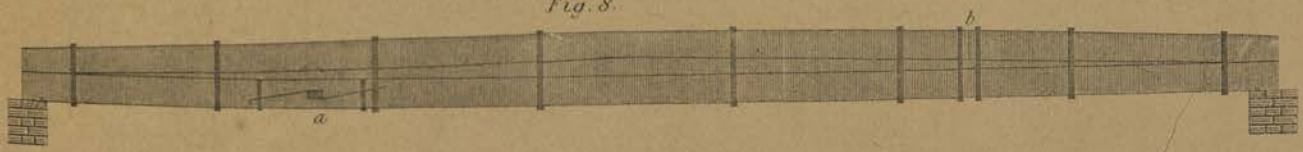


Fig. 10

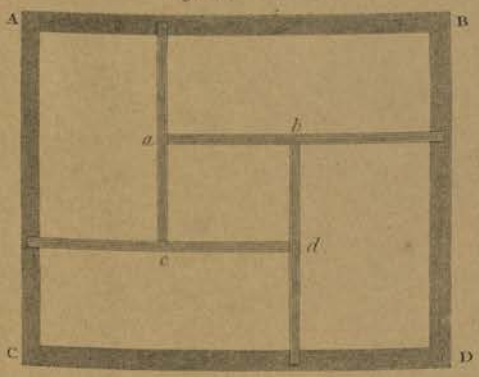
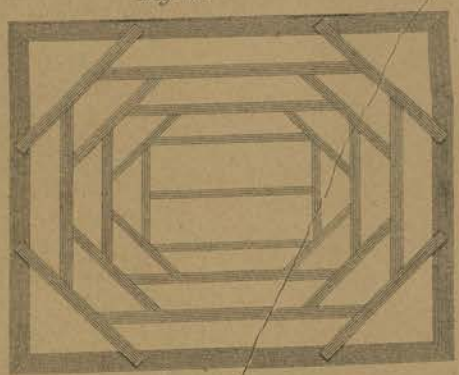


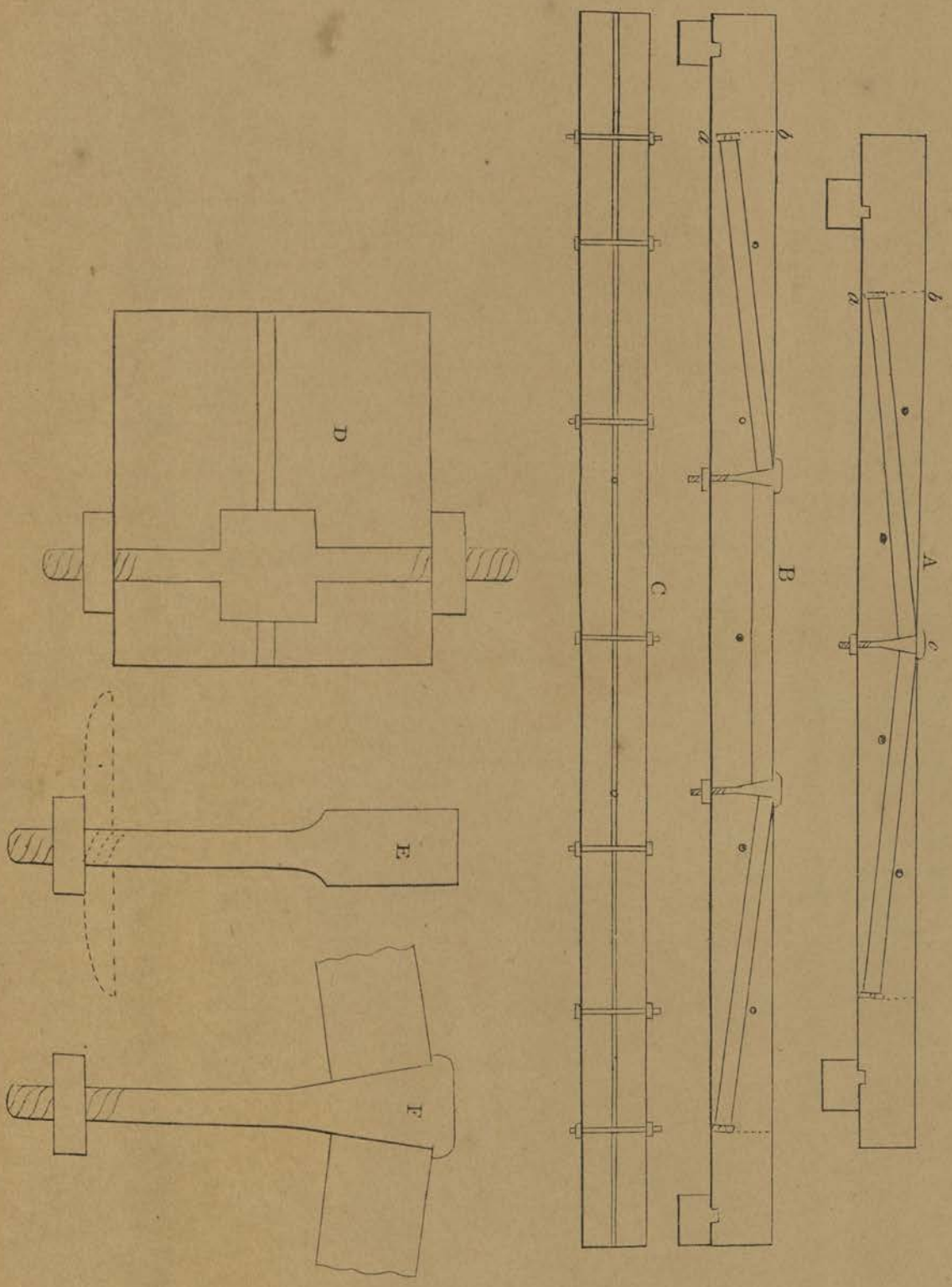
Fig. 11.



Drawn by R. Redgeld.

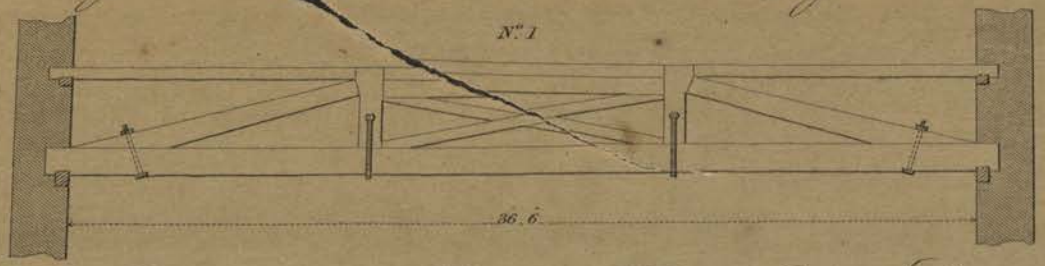
Engraved by James Davis

Crosby Lockwood & Co 7, Stationers Hall Court, Ludgate Hill, London, E.C.

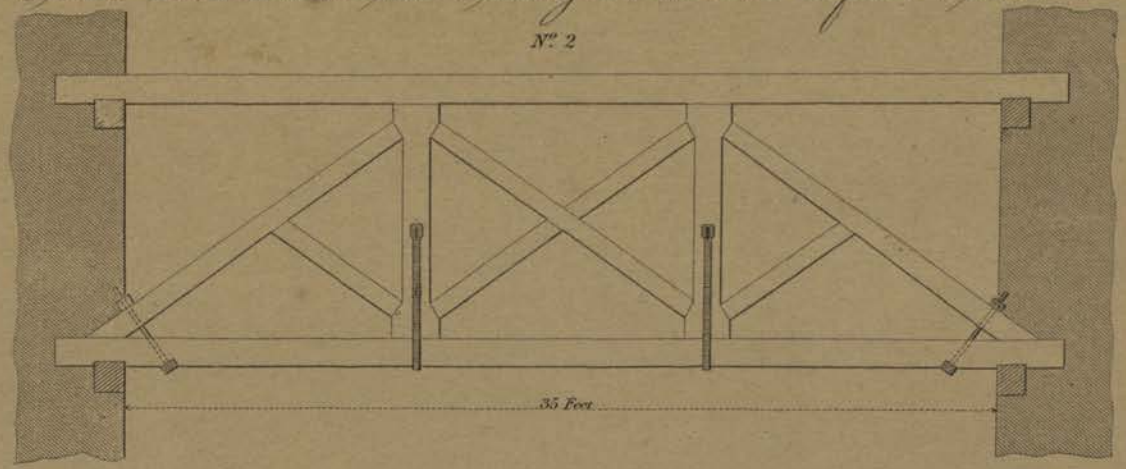


Crosby Lockwood & Co 7 Stationers Hall Court Ludgate Hill London EC

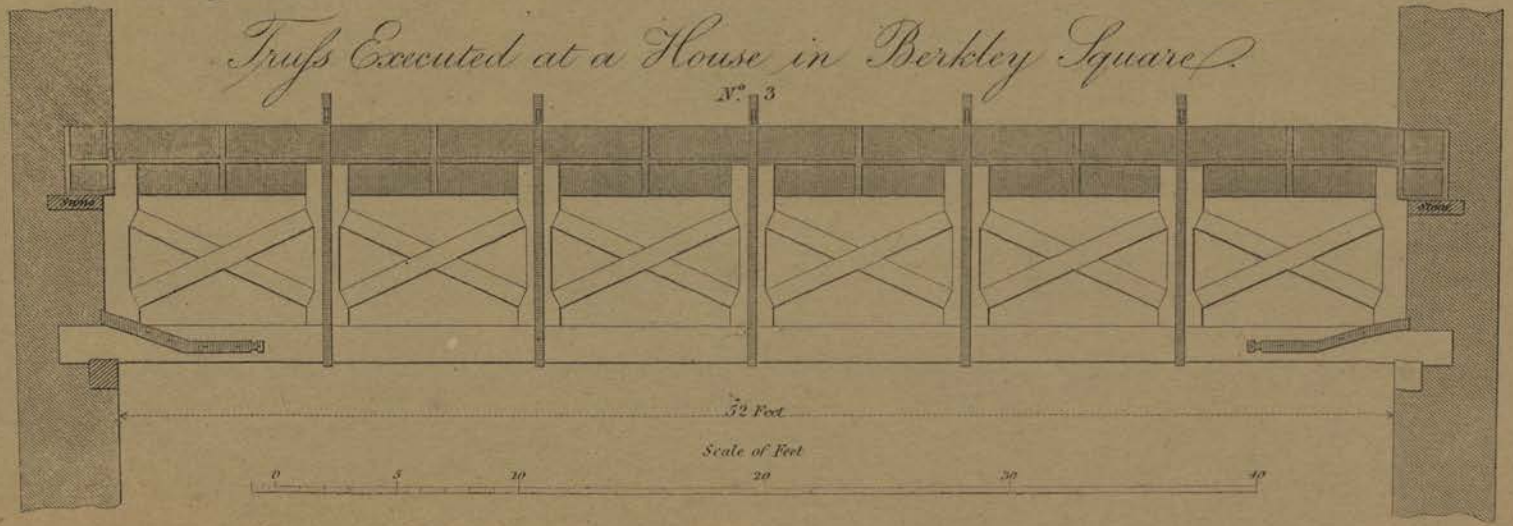
Truss Exe[illegible] the Thames Plate Glass Works.



Truss Executed at the Princess's Theatre, Oxford Street.



Truss Executed at a House in Berkley Square.



Chas. Stew.r Duncan

Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, London, E.C.

W.m A. Beever, Sc.

Roofs.

PLATE VII.

Fig. 1.

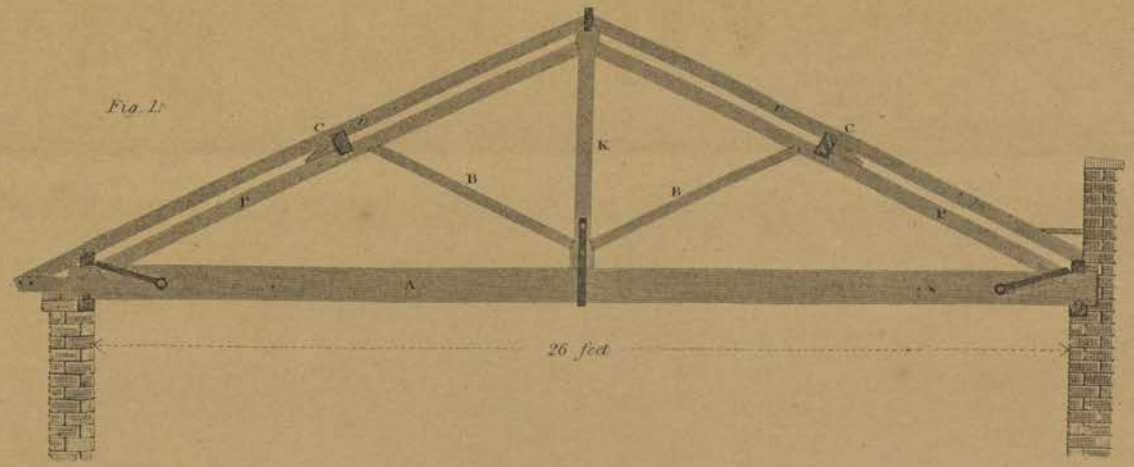
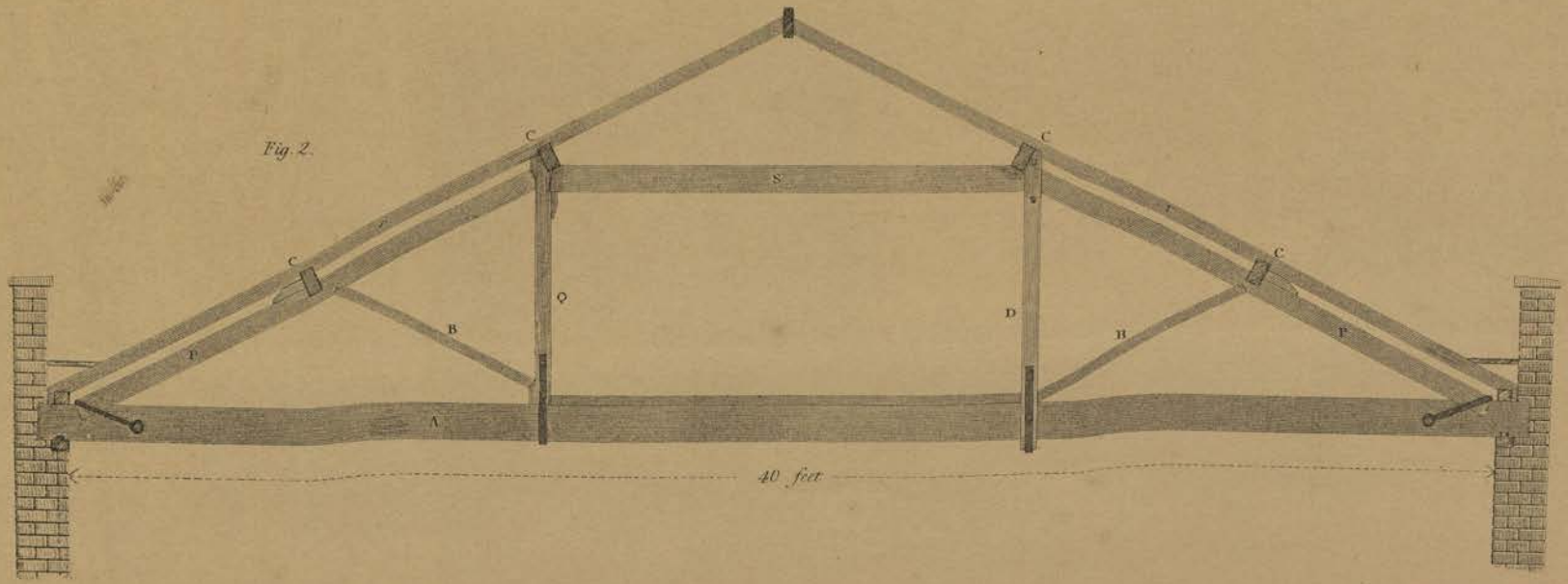


Fig. 2.



Drawn by R. Podgeld.

Engraved by James Davis.

Crosby Lockwood & Co 7 Stationers Hall Court Ludgate Hill London E.C.

TRUSS OF ROOF, 103 GREAT RUSSELL STREET BLOOMSBURY WITH DETAILS.

Fig. 1.

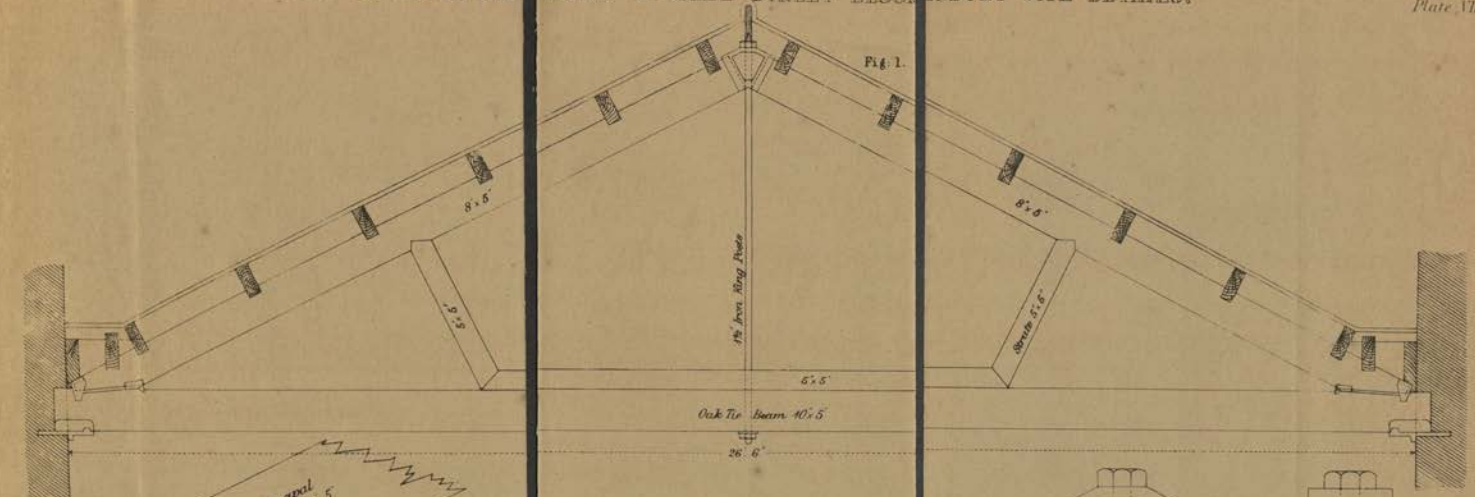
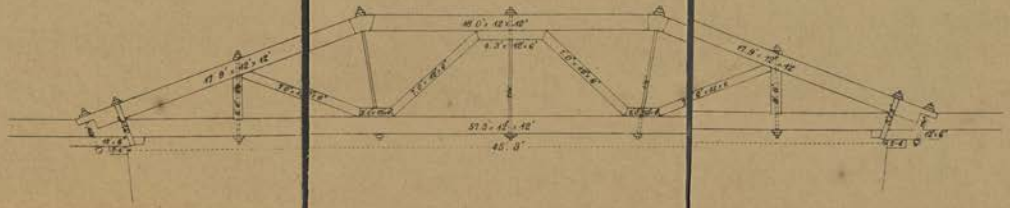

8" x 5"
1¼" Iron King Posts
8" x 6"
Struts 5" x 5"
5" x 5"
Oak Tie Beam 10" x 5"
26' 6"
Principal Rafter 8" x 5"
Cast iron Shoe
Oak Tie Beam 10" x 5"
Iron Corbels to Tie Beams and Shoes to Principals
Scale ½ inch = 1 Foot.
Scale for Details 1½ inch = 1 Foot.
Principal Rafter
1¼" King Bolt
King Bolts

Fig. 2.

TRUSS OF FOOTBRIDGE OVER FARNHAM & ALTON RAILWAY



ROYAL INSTITUTE OF BRITISH ARCHITECTS LIBRARY BOMBAY BRANCH

Crosby Lockwood & Co. 7, Stationers' Hall Court, Ludgate Hill.

Roofs.

Fig. 1.

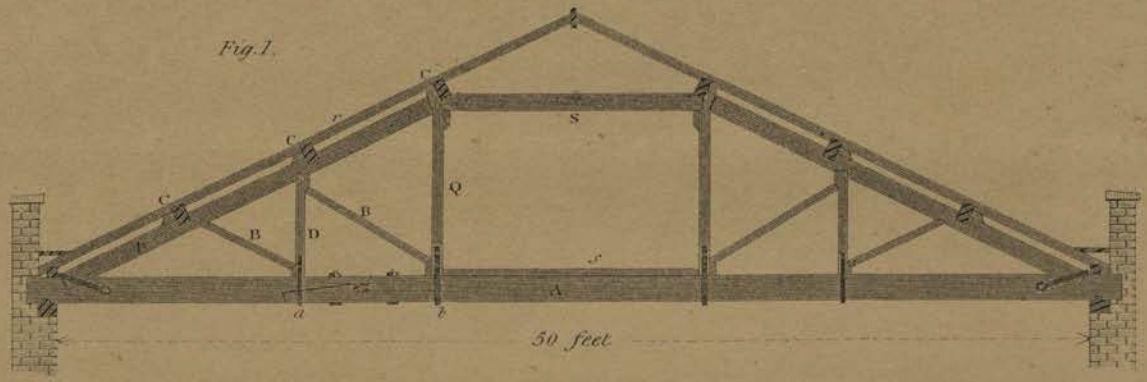
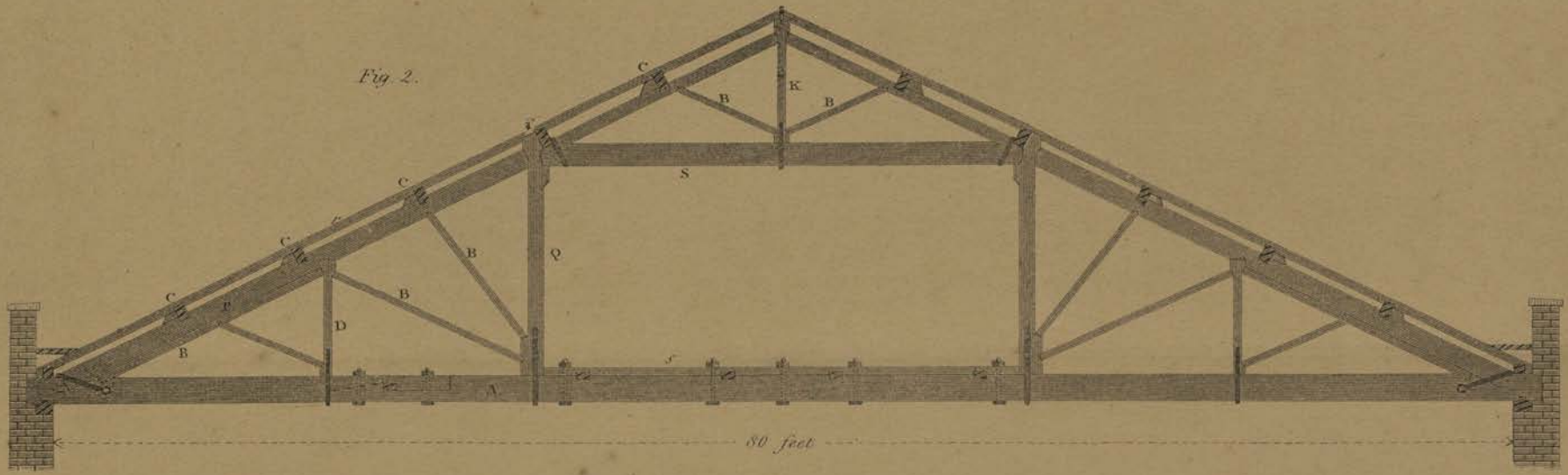


Fig. 2.



Drawn by R. Tredgold.

Engraved by James Davis.

Crosby Lockwood & Co.ª 7, Stationers Hall Court, Ludgate Hill London. E.C.

Roofs.

Fig. 1.

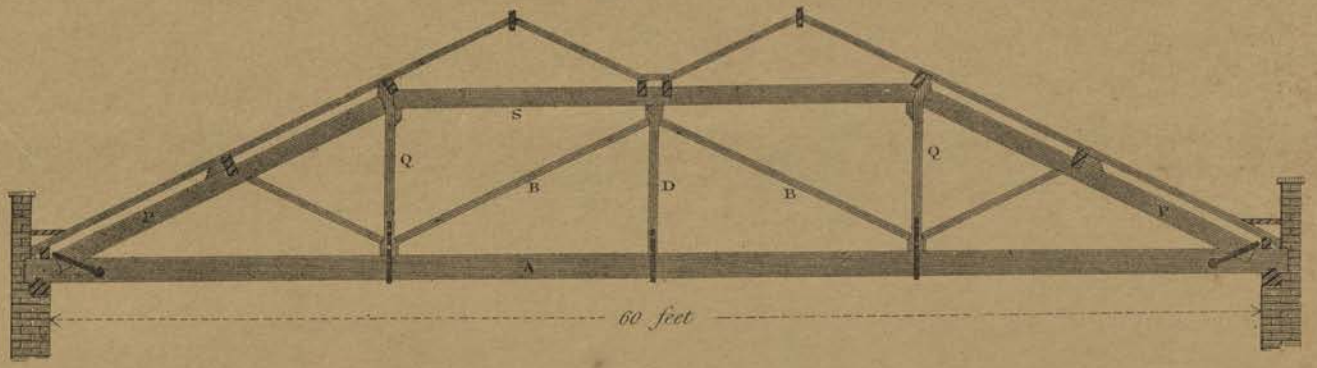
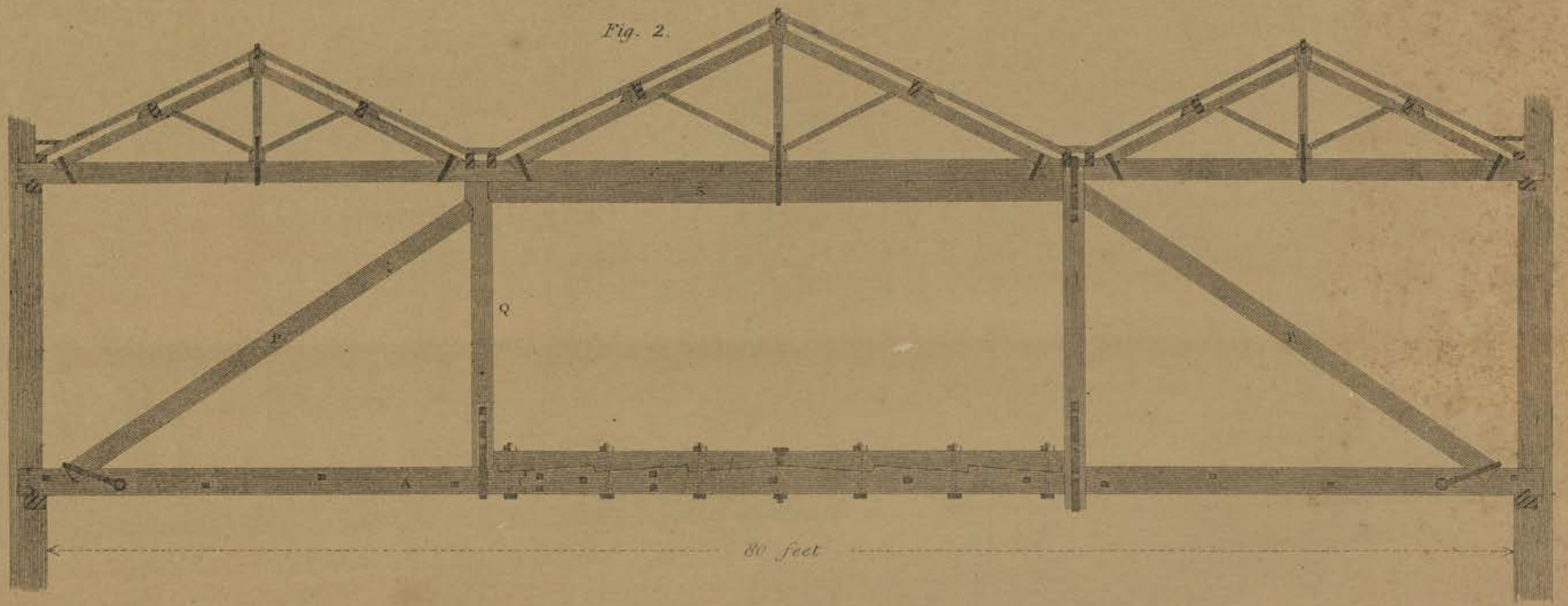


Fig. 2.



Drawn by E. Tredgold.

Engraved by James Davis.

Crosby, Lockwood & Co 7, Stationers Hall Court, Ludgate Hill, London, E.C.

Roofs that have been executed.

Roof of the Basilica of St. Paul at Rome

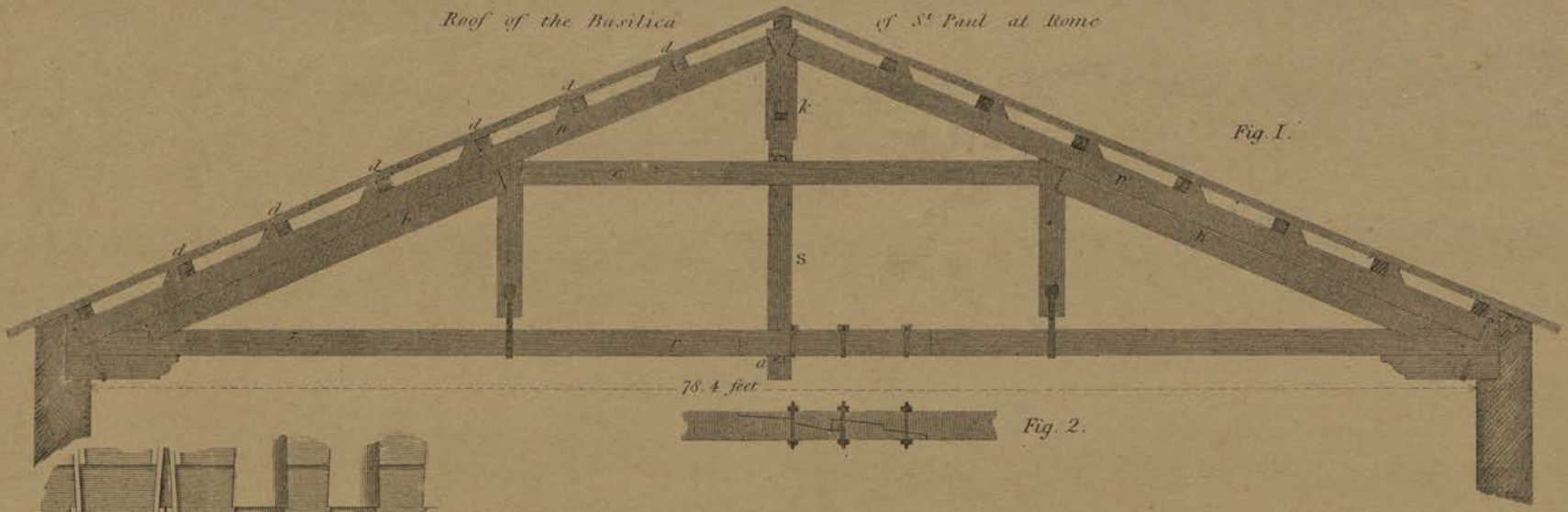


Fig. I.

Fig. 2.

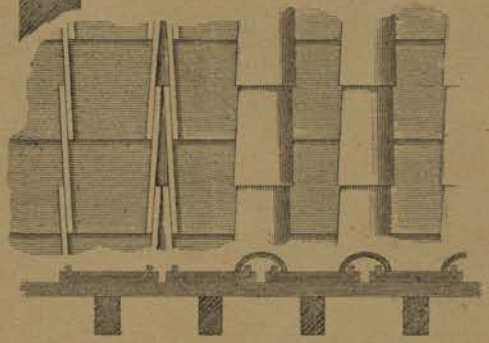


Fig. 3.

Roof of the Theatre d'Argentina at Rome

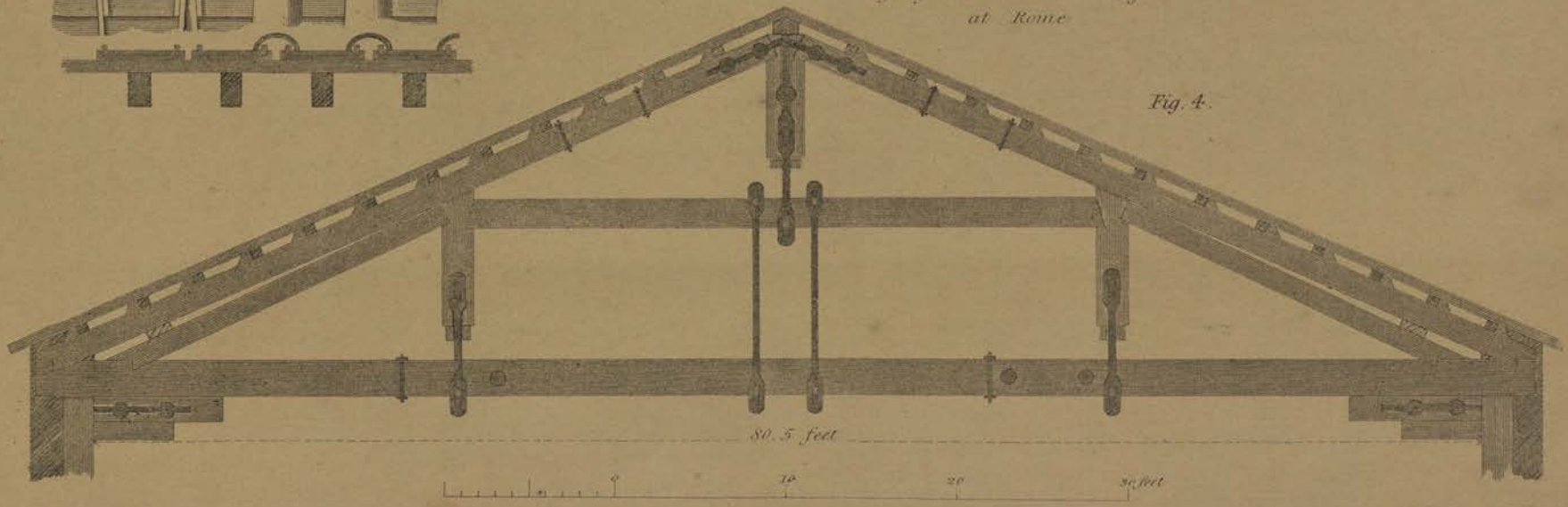


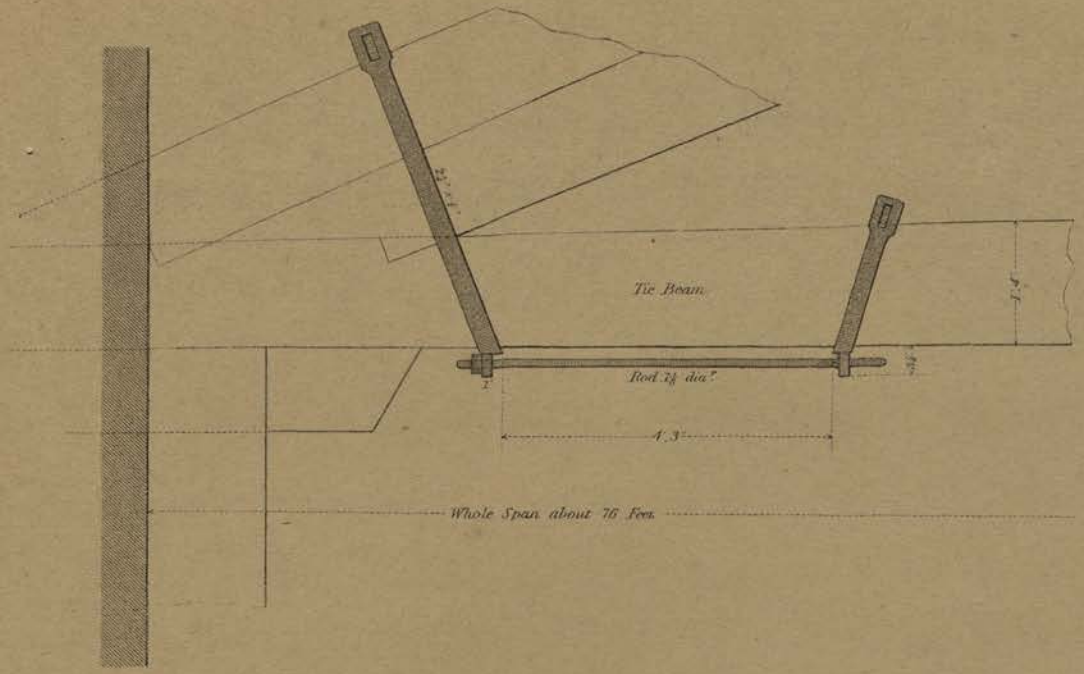
Fig. 4.

Drawn by R. Tredgold.

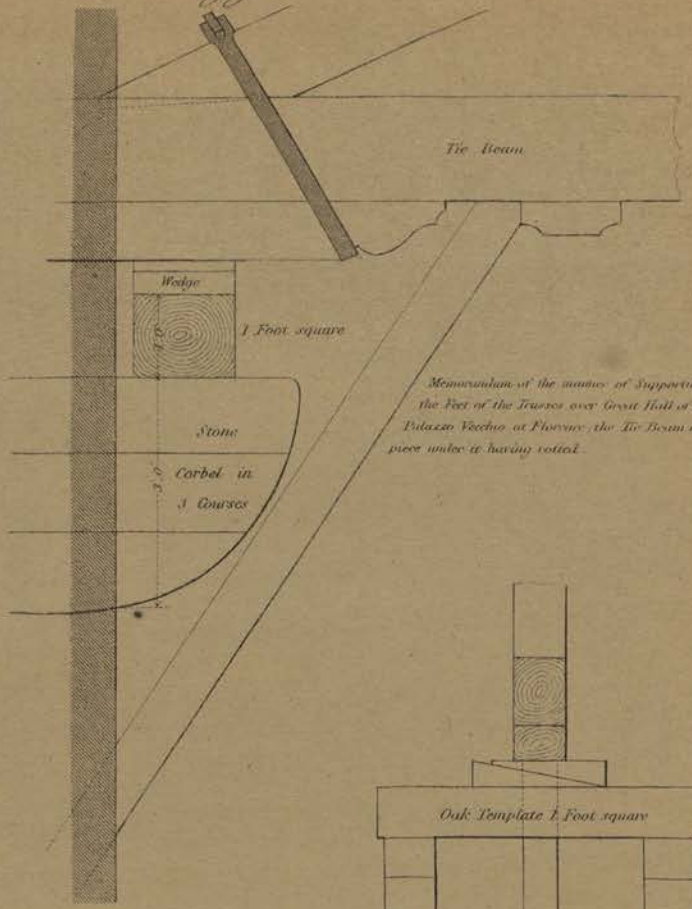
Engraved by James Davis

Crosby Lockwood & Co. 7 Stationers Hall Court Ludgate Hill London E.C.

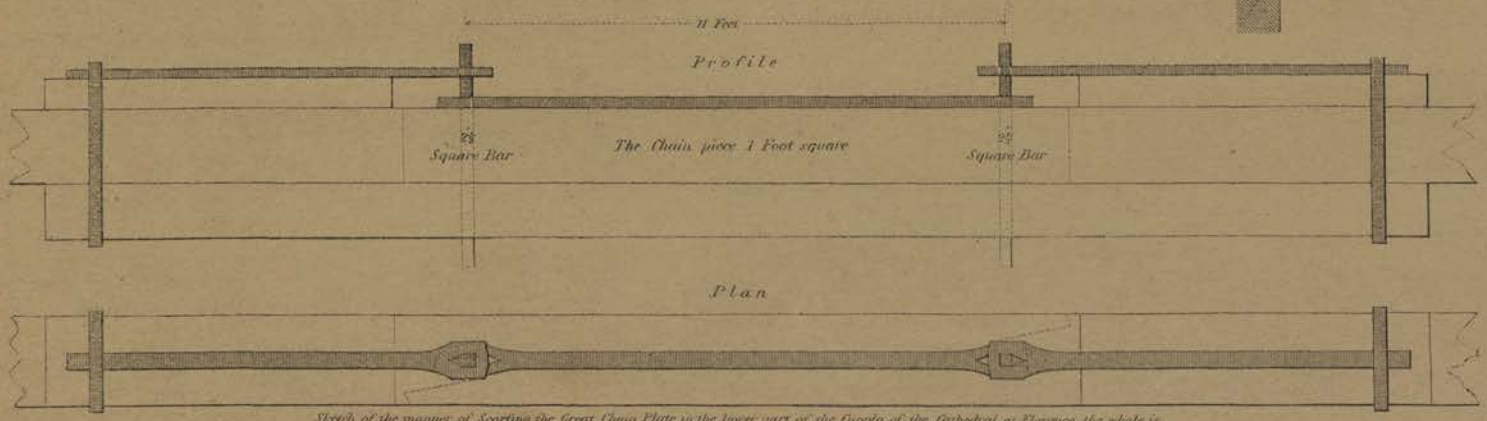
Foot of Truss of Roof over the New Theatre at Ancona.



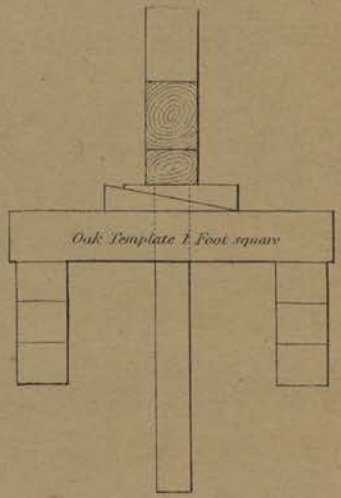
Palazzo Vecchio – Florence.


Tie Beam
Wedge
1 Foot square
Stone
Corbel in
3 Courses
Memorandum of the manner of Supporting the Feet of the Trusses over Great Hall of the Palazzo Vecchio at Florence, the Tie Beam and piece under it having rotted.

Cathedral – Florence.



Sketch of the manner of Scarfing the Great Chain Plate in the lower part of the Cupola of the Cathedral at Florence, the whole is so much Plaster over with Iron as the only visible part that this Sketch is necessarily very imperfect.



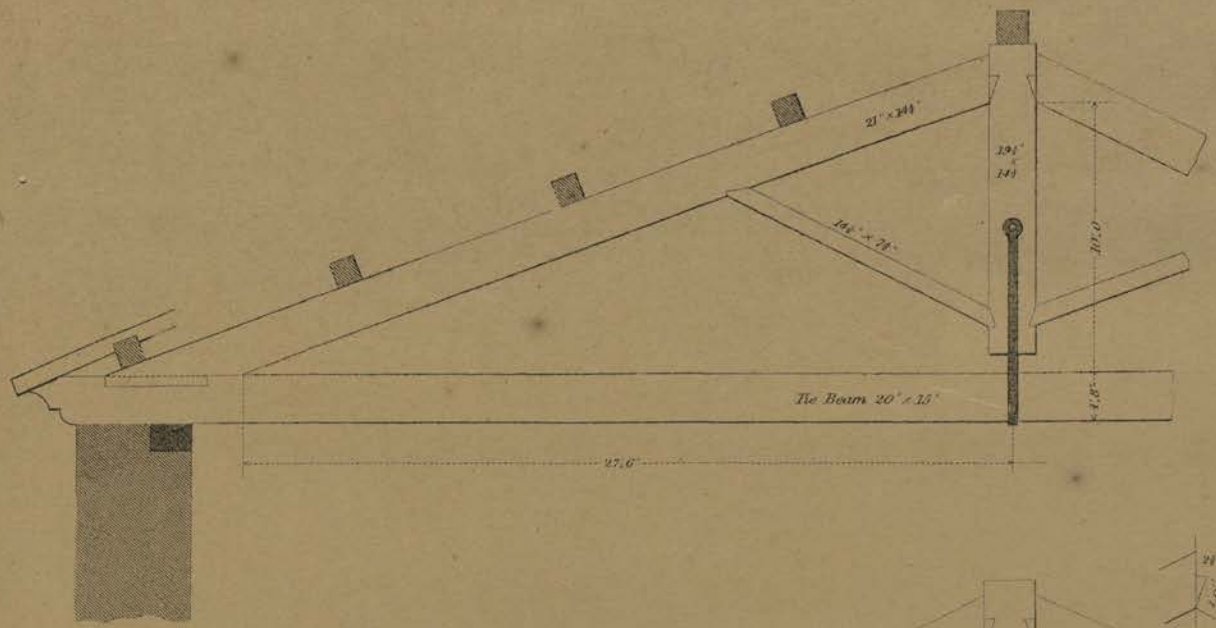
Memoranda of Carpentry. (Measured and Drawn by S. Smirke, Architect.)

Drake, Lockwood & Co.ª 7 Stationers Hall Court Ludgate Hill London

Cathedral at Leghorn

Measured and Drawn by S. Smirke Architect

PLATE XIII.

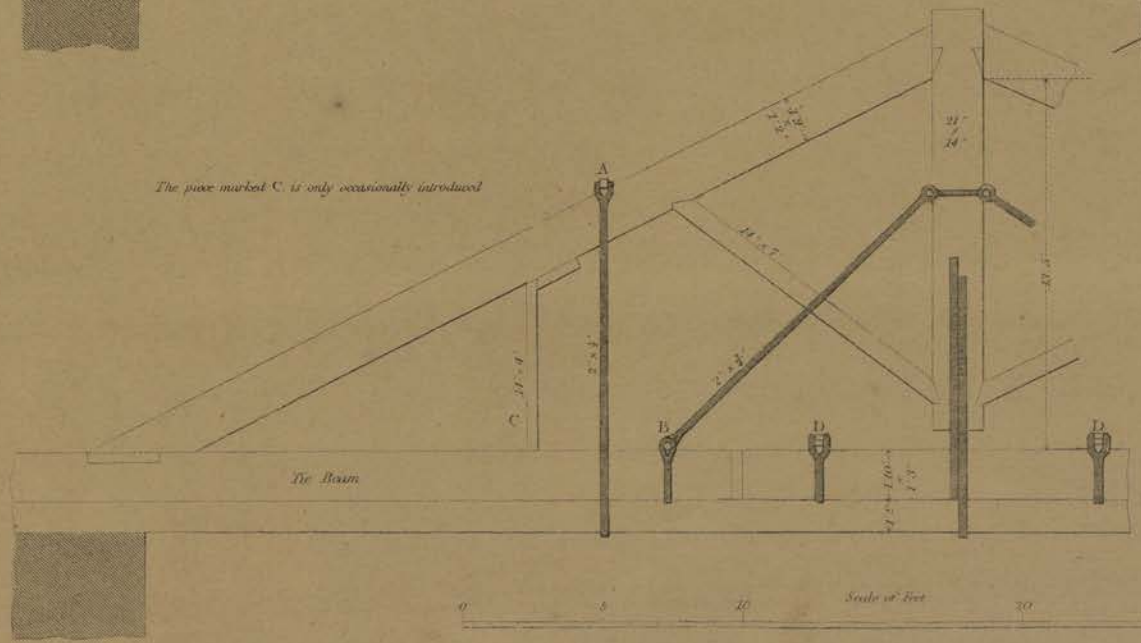


Trusses of the Roof over Cathedral at Leghorn they are in Pairs one Foot clear of each other; the Hatter one carries the Purlines of Roof, the other carries the Ceiling which is an extremely heavy Framing of Wood, with Panels sunk several Feet, it is attached to the Truss in various ways according to circumstances sometimes suited to Bindars, in other places held up by Rods of Iron to different parts of the Truss. Each pair of Trusses are about 15½ Feet apart.

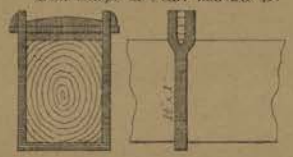
Part at Large marked A.

Part at Large marked B.

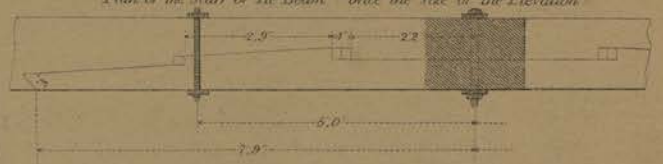
The piece marked C. is only occasionally introduced



Iron Clasps at Scarf marked D.



Plan of the Scarf of Tie Beam twice the size of the Elevation



0 5 10 Scale of Feet 20 30

Crosby Lockwood & Co. 7, Stationer's Hall Court, Ludgate Hill, London E.C.

W. J. Beever Sc.

Section of Roof of New Saloon – Academy of Arts – Florence.

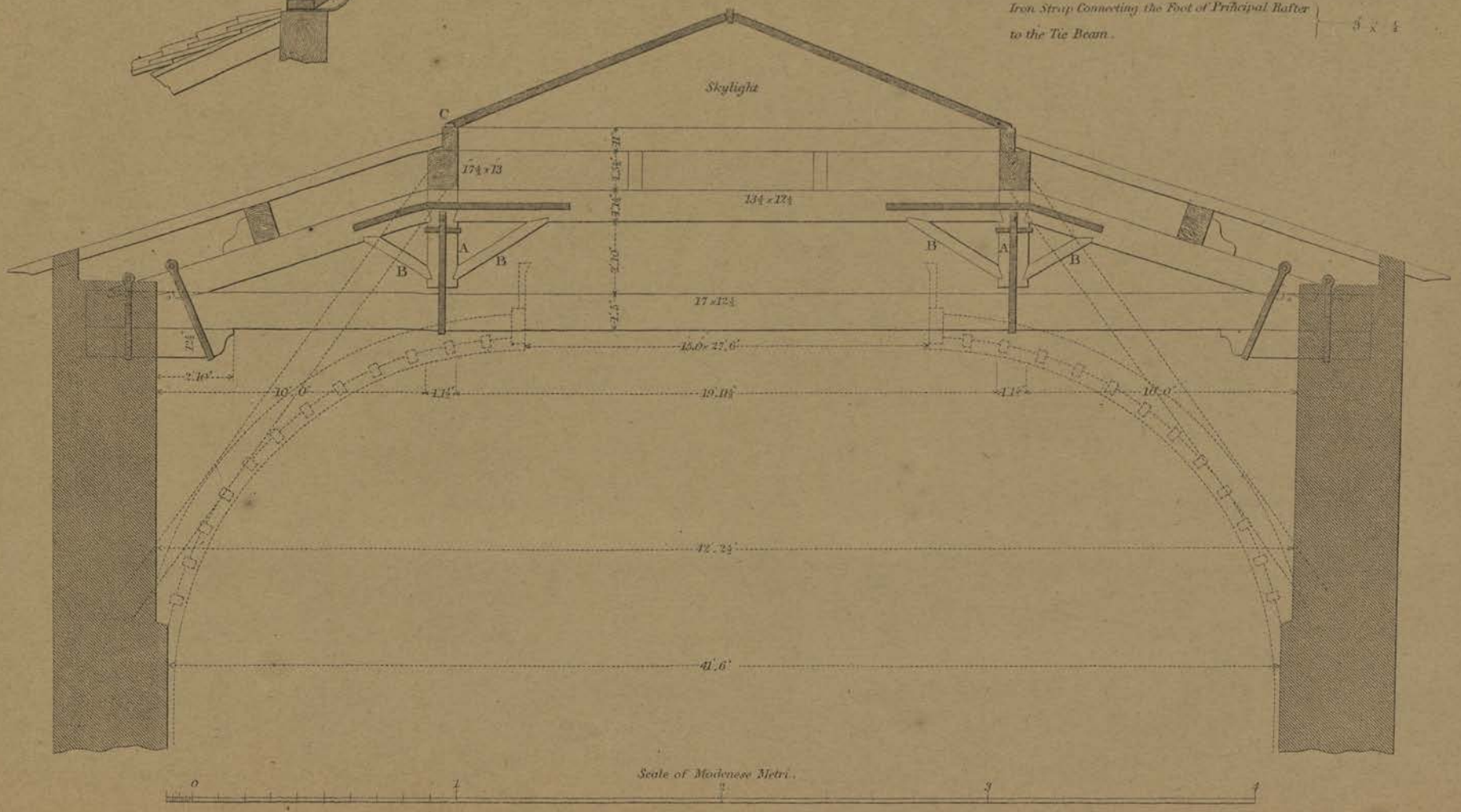
PLATE XIV.

(From Measurements taken by Sydney Smirke, Architect.)

Part C at Large

Wrought Iron Rafter 3 × ¼

A. Queenposts	13½ × 12
B.B. Braces	12 × 4½
Iron Strap Connecting the Queens to the Tie Beam	3 × ¼
Iron Strap Connecting the Foot of Principal Rafter to the Tie Beam.	3 × ¼



Scale of Modenese Metri.

0 1 2 3 4

(1 One Metre of Modena equal to about 3.33 English Measure.)

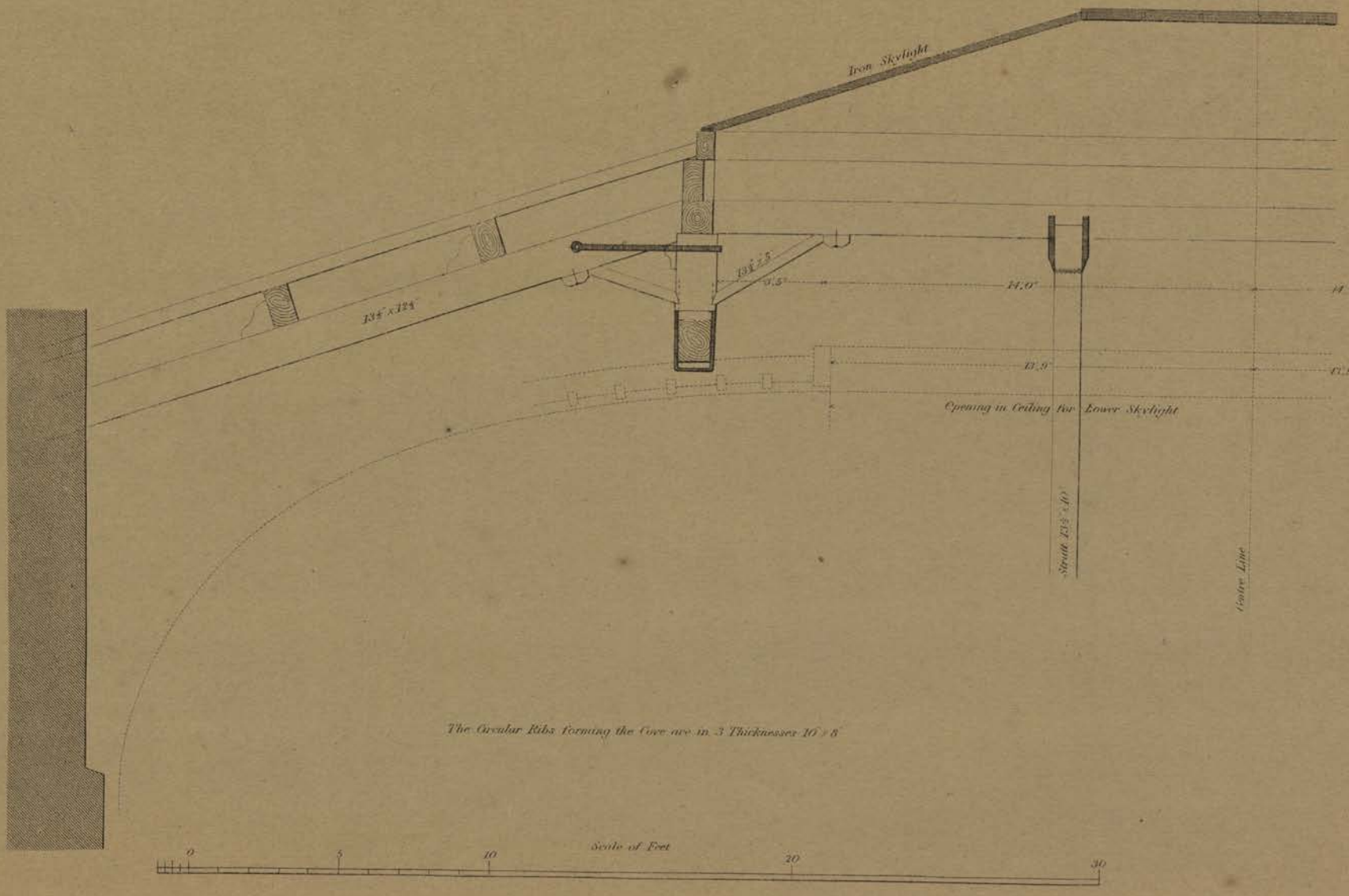
Crosby Lockwood & Co. 7 Stationers Hall Court, Ludgate Hill, London E.C.

W. J. Hooper, Sc.

Longitudinal Section of Roof of New Saloon, Academy of Arts—Florence.

PLATE XV.

(Measured and Drawn by S. Smirke Architect.)

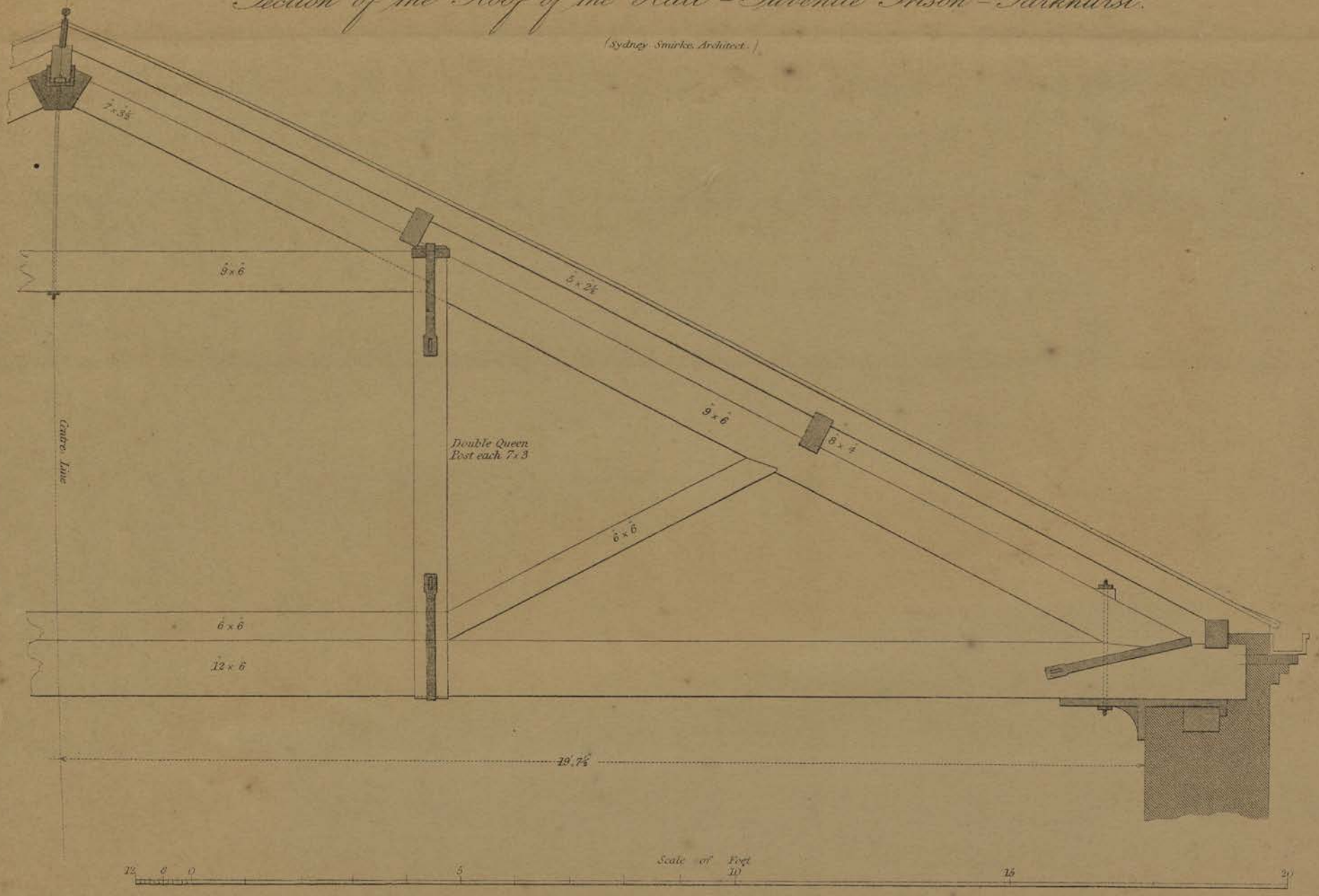


Crosby Lockwood & Co. 7 Stationers Hall Court Ludgate Hill London E.C.

W. A. Brewer Sc.

Section of the Roof of the Hall - Juvenile Prison - Parkhurst.

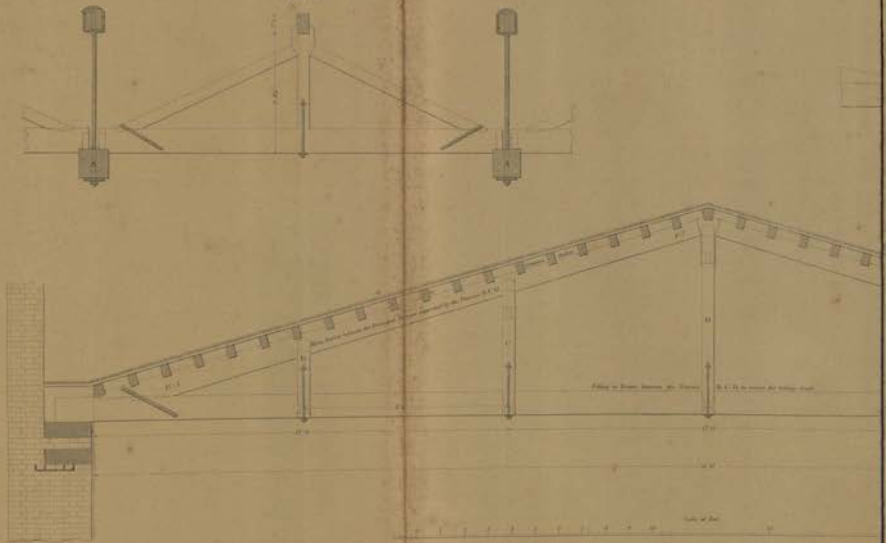
(Sydney Smirke, Architect.)



Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, London, E.C.

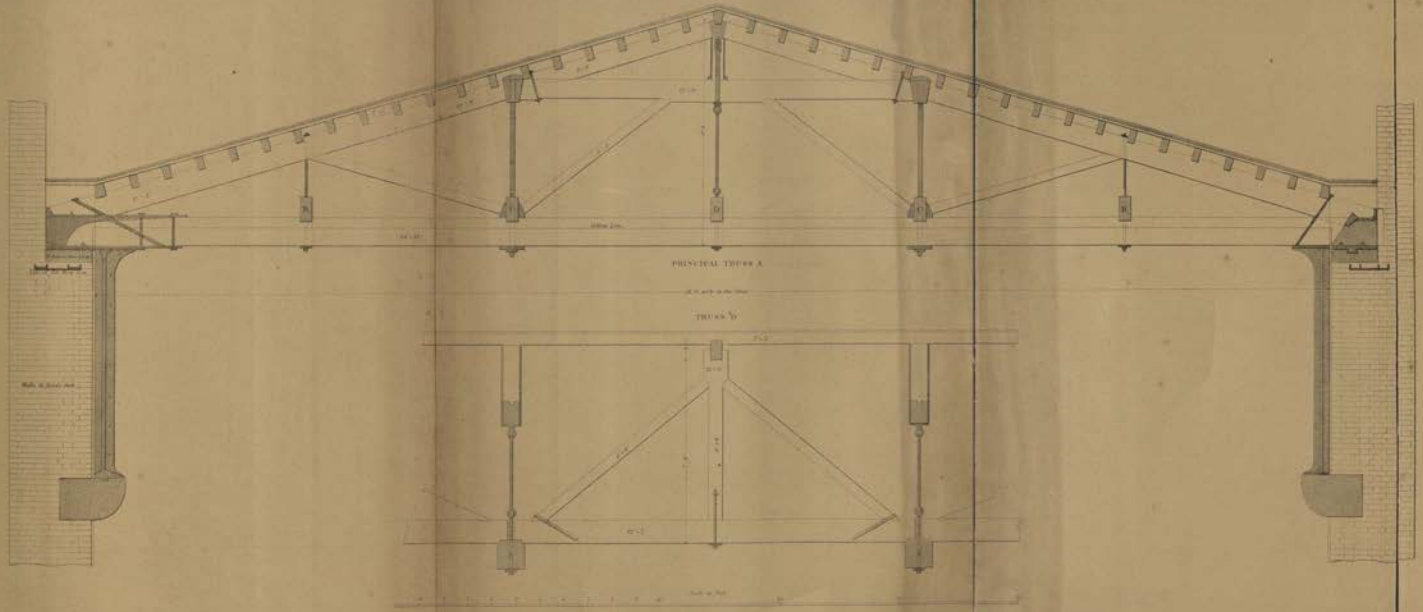
W. A. Becker, Sc.

Christs Hospital, Hull



Christs Hospital, Hall.

DETAILS OF ROOF, 1824

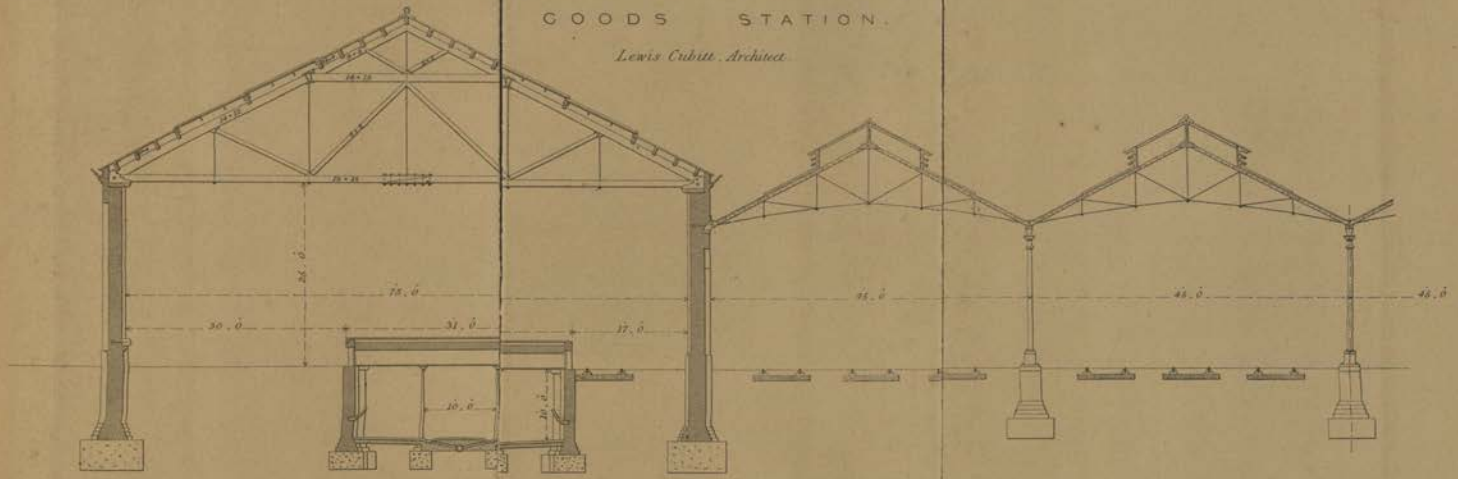


GREAT NORTHERN RAILWAY.

LONDON TERMINUS

GOODS STATION.

Lewis Cubitt, Architect.



TRANSVERSE SECTION THROUGH HALF OF GOODS DEPÔT - DOWN SIDE

SHOWING WEST WAREHOUSE WITH PLATFORM & STABLES UNDER

THE OTHER HALF OF GOODS DEPÔT IS USED FOR GOODS ARRIVING,

AND IS SIMILAR TO THIS.

10 5 0 10 20 30 40 50 100 Feet.

Crosby Lockwood & Co. 7 Stationers' Hall Court Ludgate Hill London E.C.

W. A. Beever Sc.

Roofs.

PLATE XX.

Fig. 1.

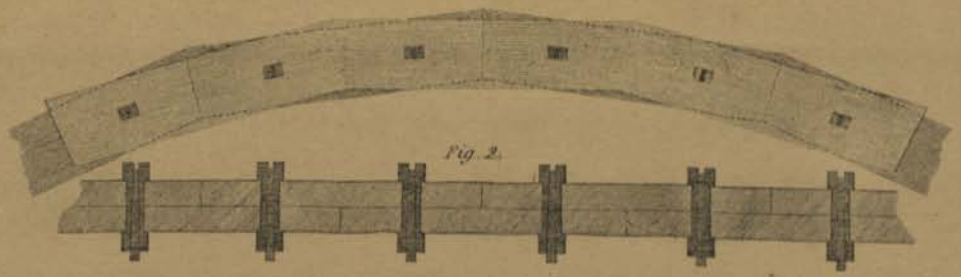


Fig. 2.

Fig. 5.

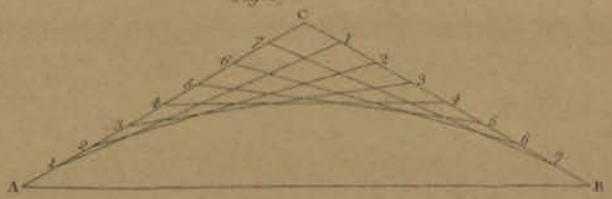


Fig. 4.

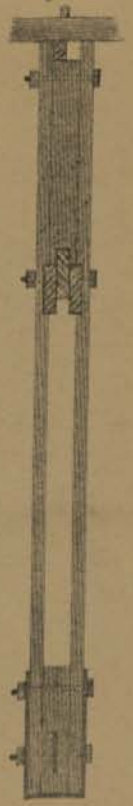


Fig. 3.

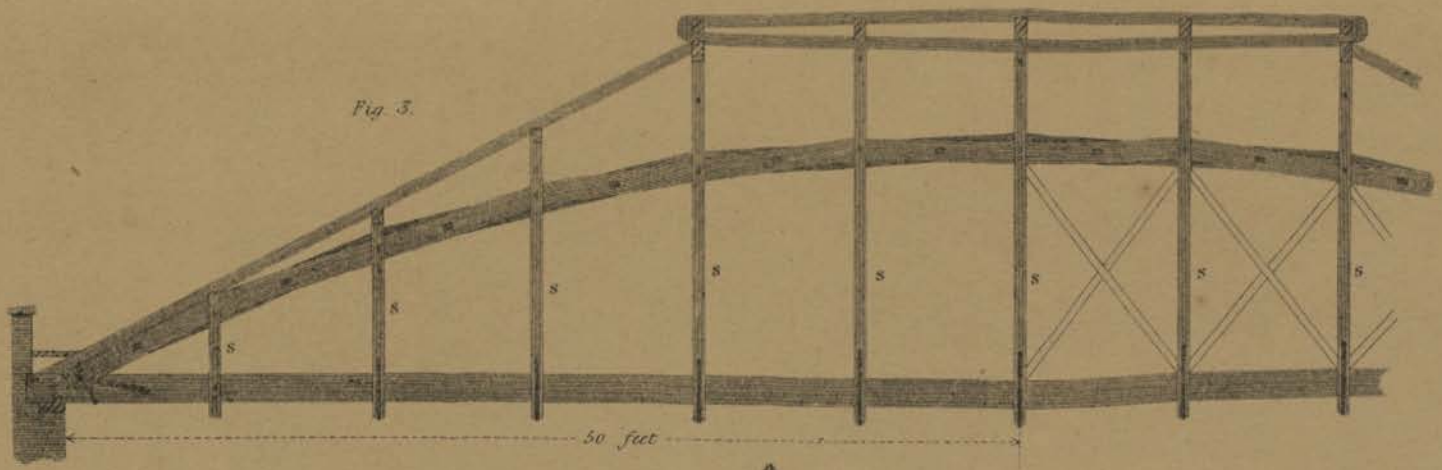
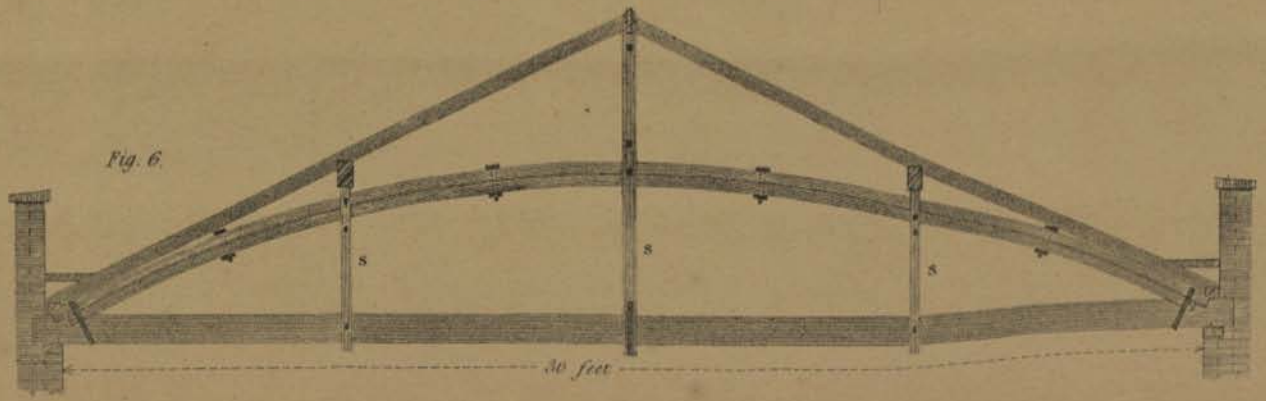


Fig. 6.

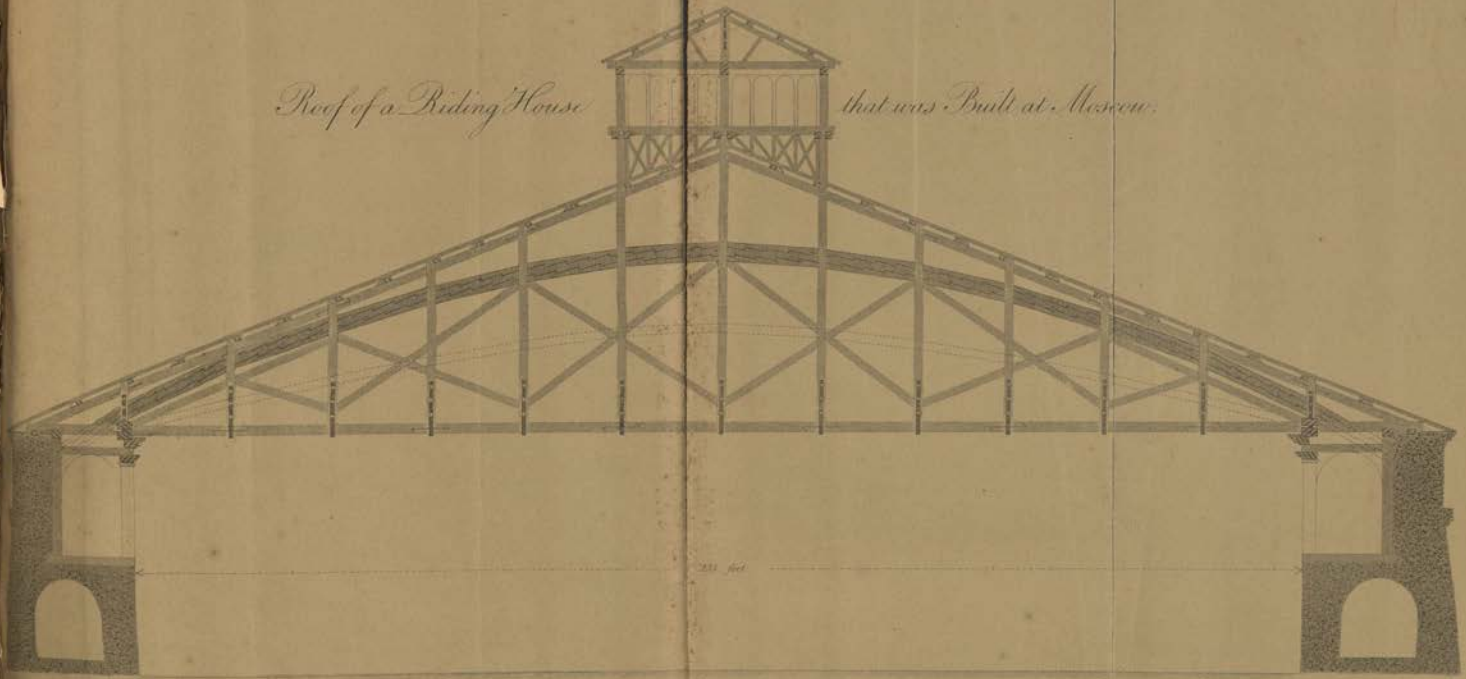


Drawn by R. Tredgold.

Engraved by James Davis.

Crosby Lockwood & Co 7, Stationers Hall Court, Ludgate Hill, London, E.C.

Roof of a Riding House that was Built at Moscow.

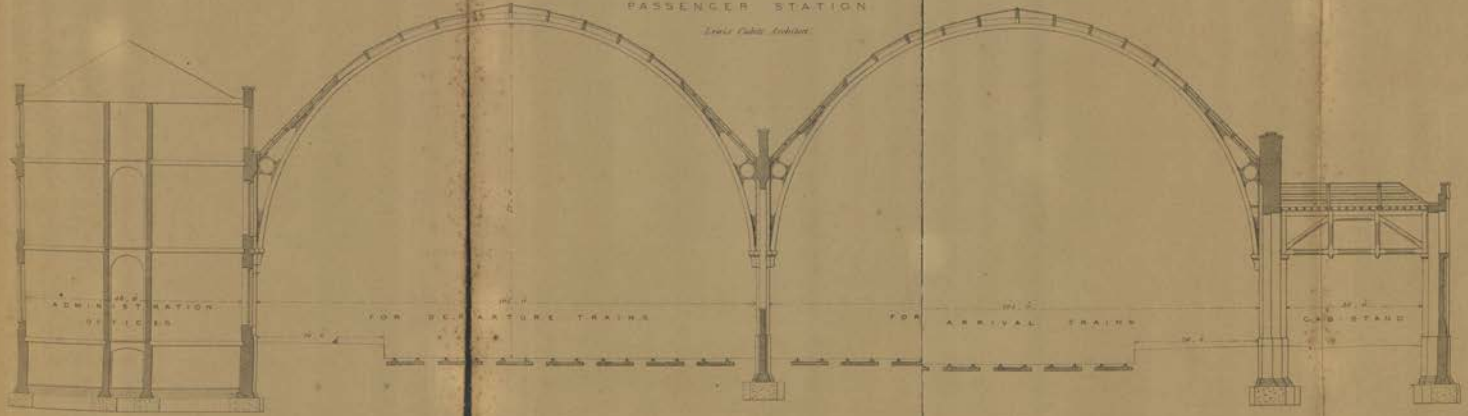


GREAT NORTHERN RAILWAY.

LONDON TERMINUS

PASSENGER STATION

Lewis Cubitt Architect

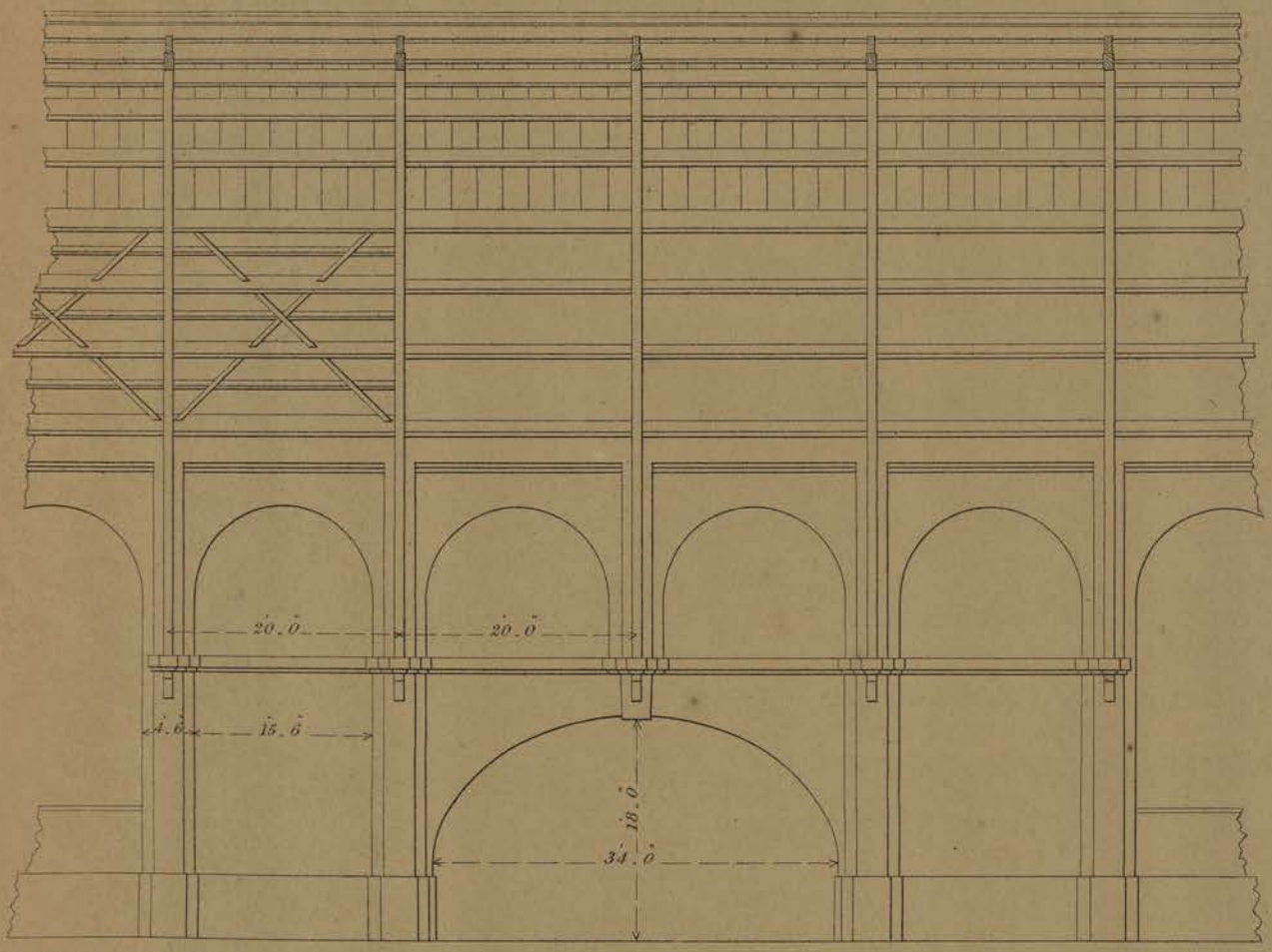


TRANSVERSE SECTION THROUGH TERMINUS

GREAT NORTHERN RAILWAY.

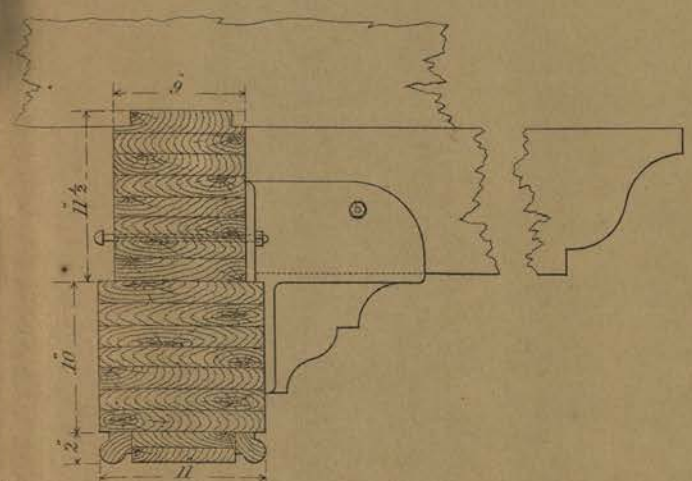
LONDON TERMINUS

PASSENGER STATION.

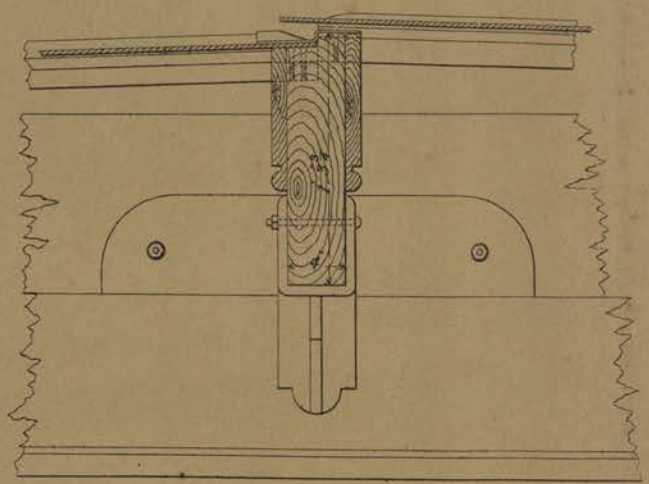


PORTION OF THE DIVISION WALL BETWEEN ROOFS - SHOWING POSITION OF RIBS

10 5 0 10 20 30 40 50 Feet.



SECTION THROUGH RIB AT CENTRE PURLIN



SECTION THROUGH PURLIN

12 9 6 3 0 1 2 3 4 5 Feet.

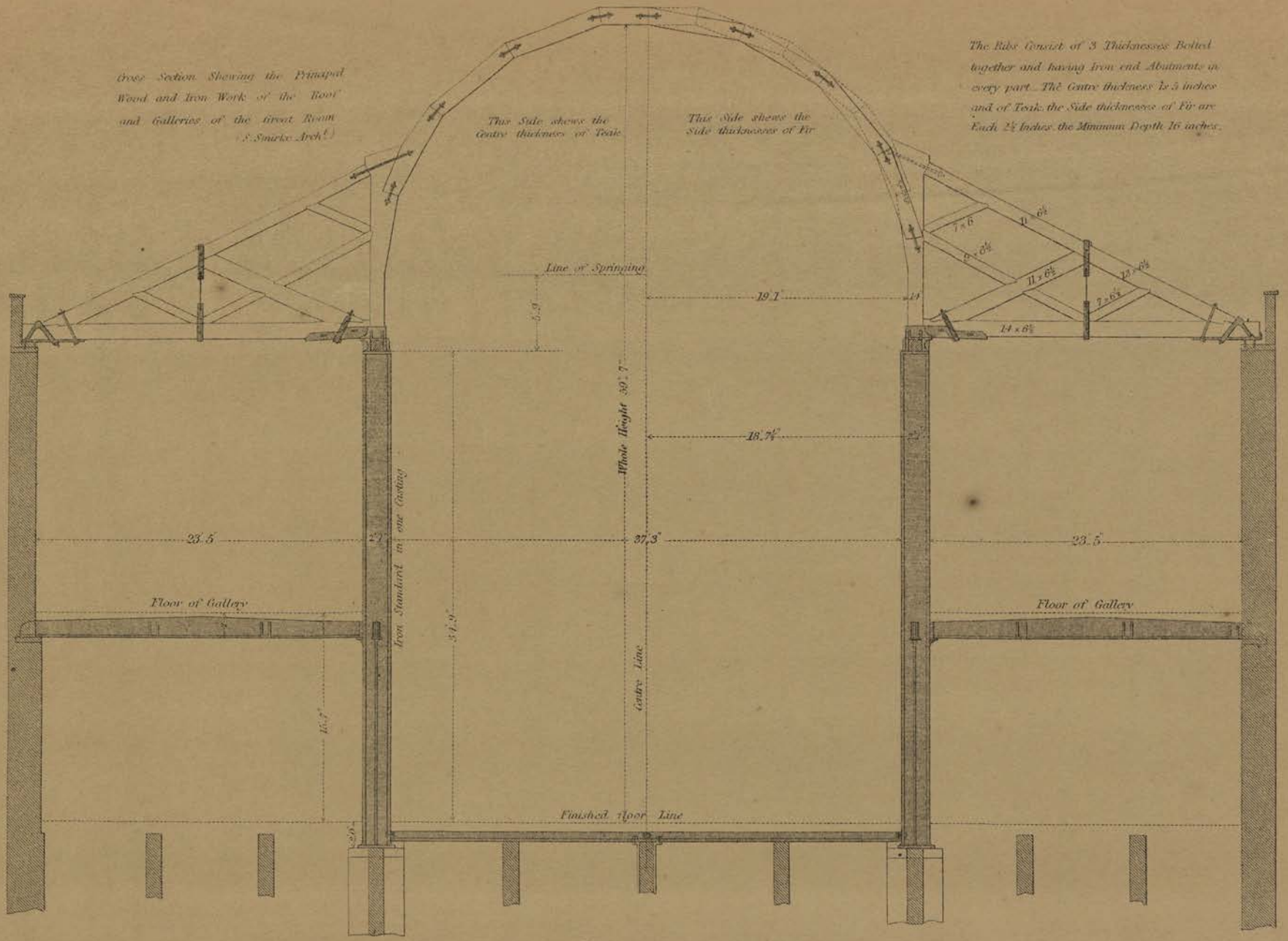
...is Cubitt. Arch^t

Crosby Lockwood & Co 7, Stationers Hall Court Ludgate Hill London. E.C.

W. A. Beever Sc

Pantheon.

PLATE XXIV.



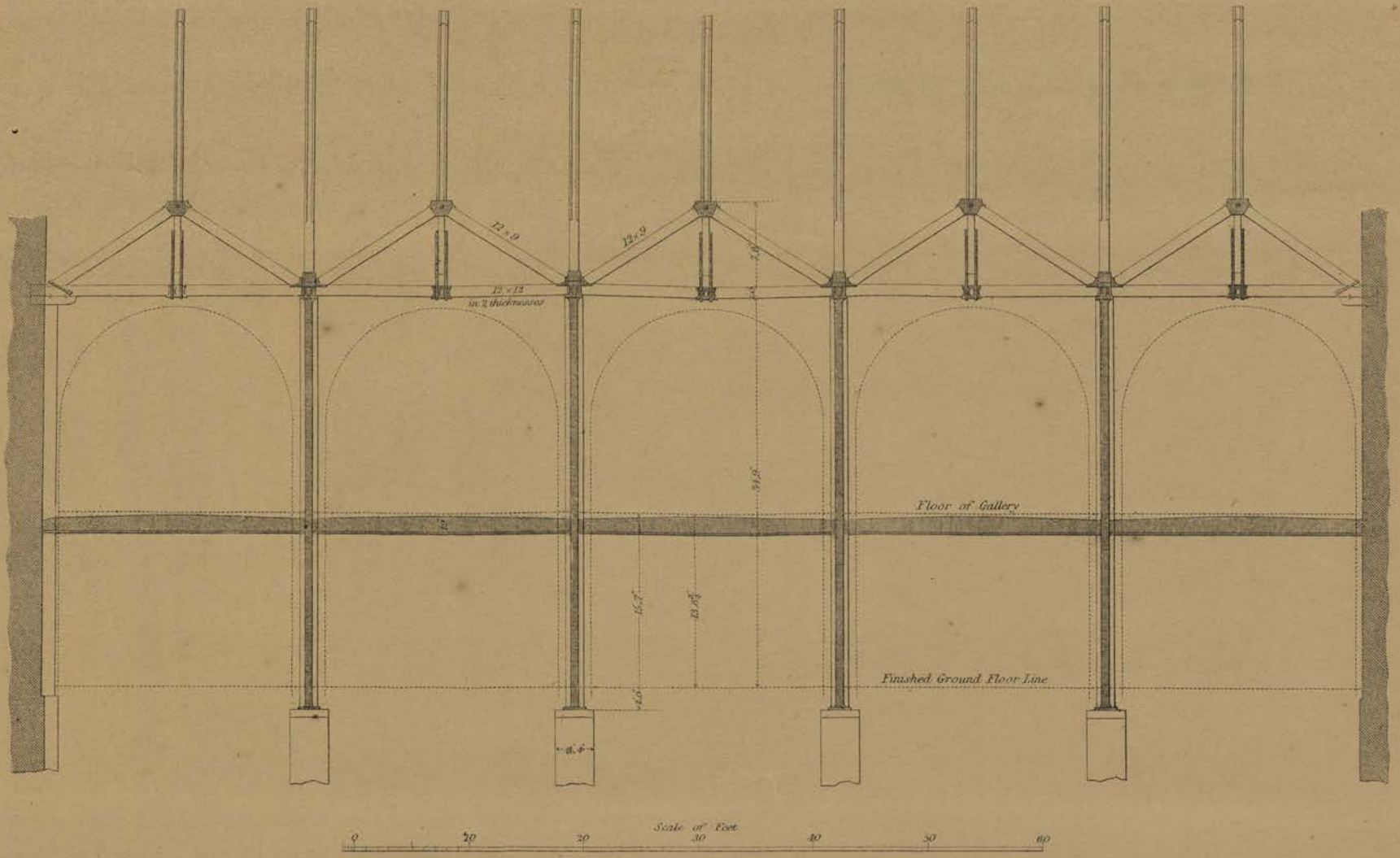
Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, London E.C.

W. A. Beever Sc.

Pantheon.

Longitudinal Section Shewing the Principal Wood and Iron Work of the Roof and Gallery of the Great Room.

(Sydney Smirke. Architect.)



Crosby, Lockwood & Co.ª 7 Stationers Hall Court, Ludgate Hill, London, E.C.

W. A. Beever Sc.

Roofs.

Fig. 1.

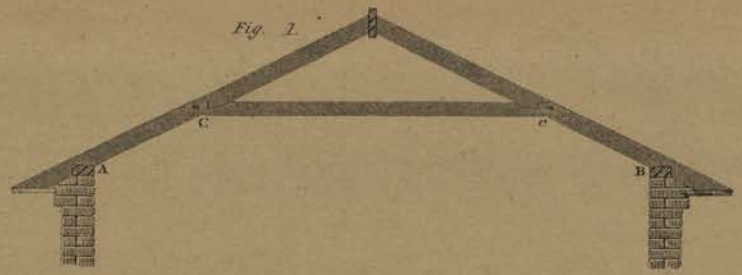


Fig. 2.

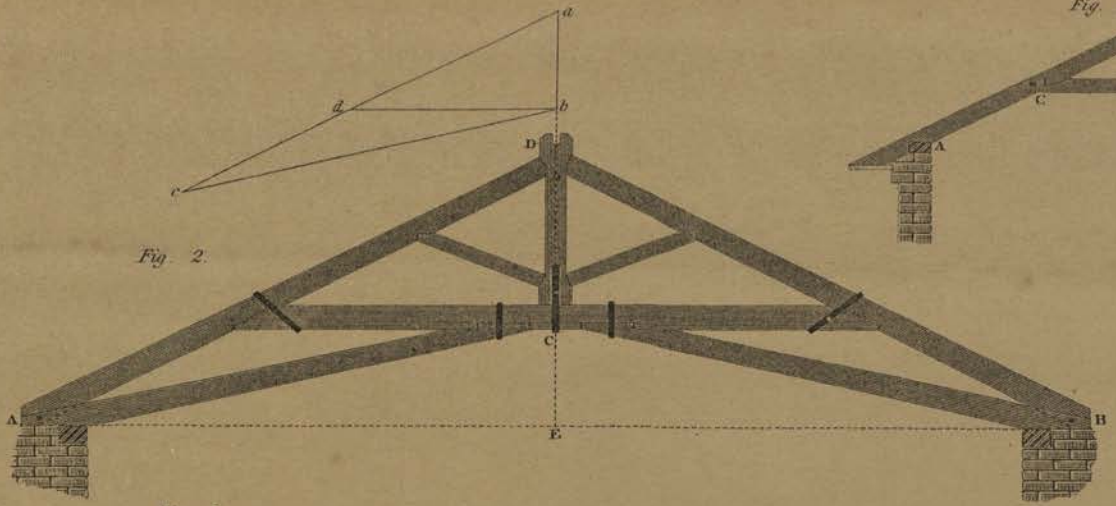


Fig. 4.

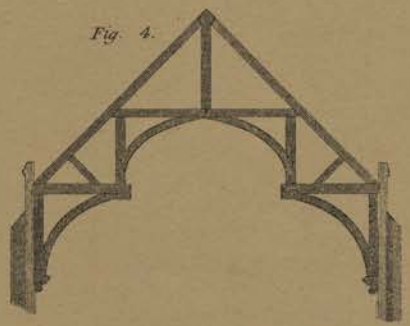


Fig. 5.

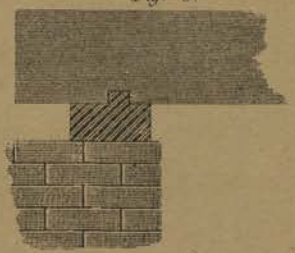
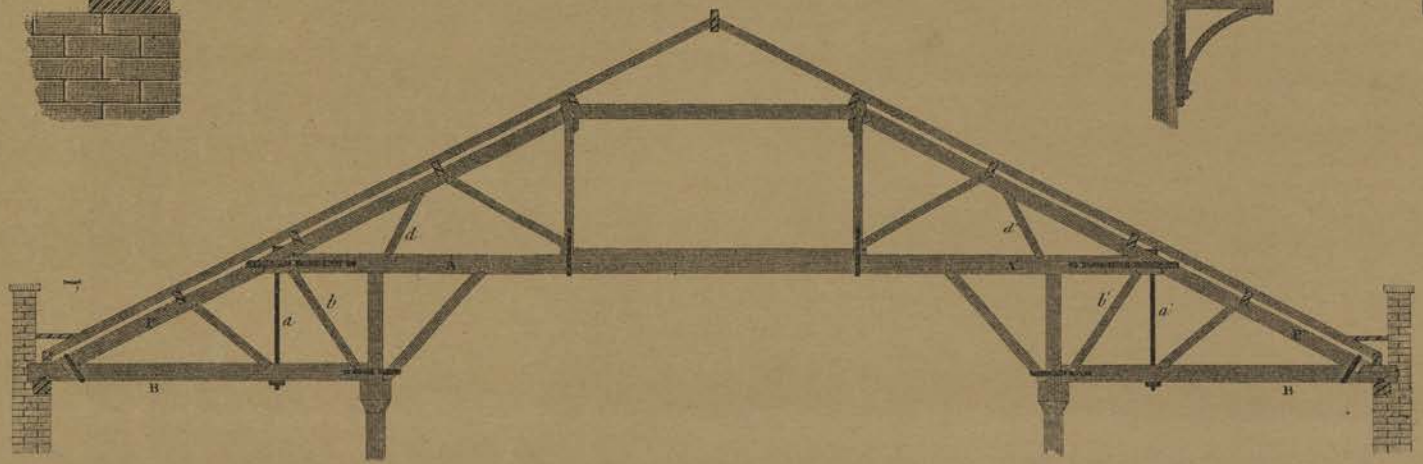


Fig. 3.



Drawn by R. Bridgold.

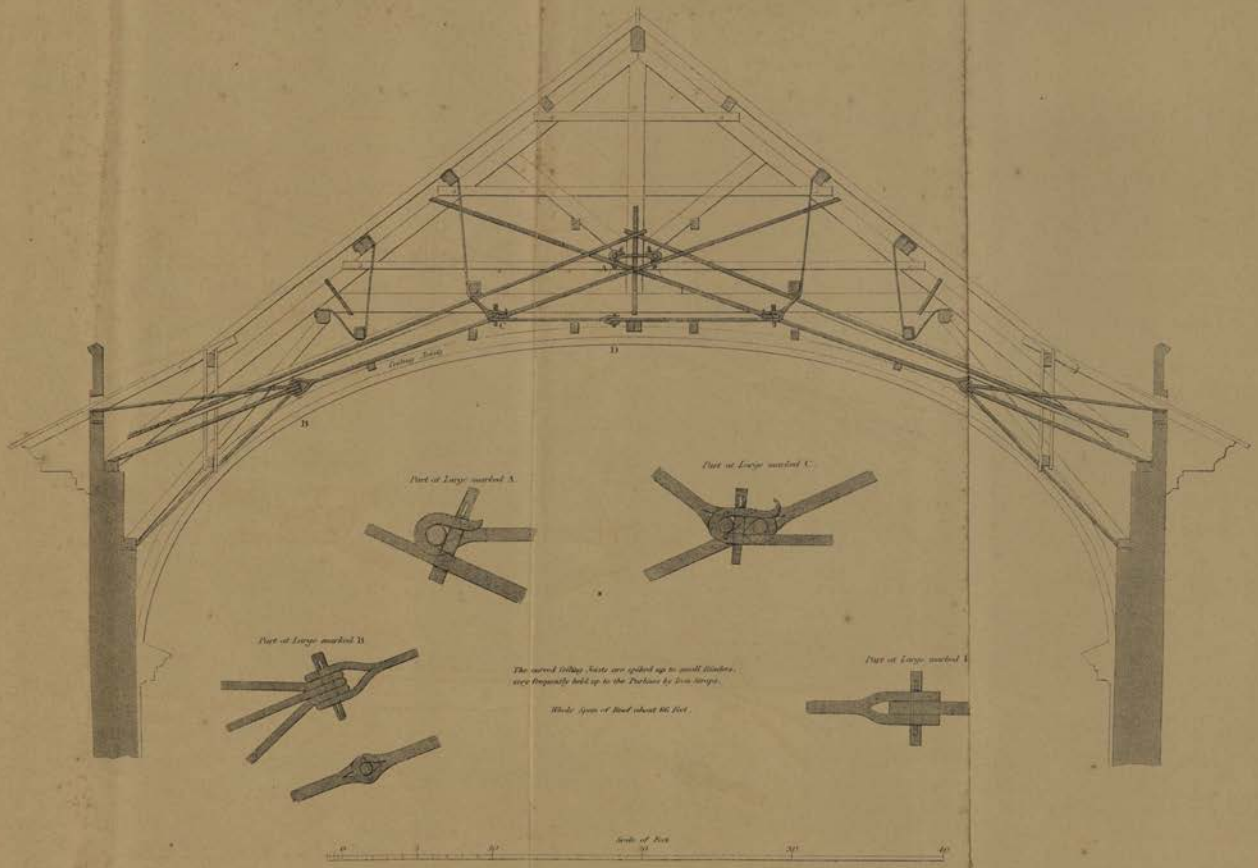
Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, London, E.C.

Engraved by James Travis.

Section of the Roof over the Exchange-Genoa.

PLATE XXVII.

Measured and Drawn by [illegible] Architect

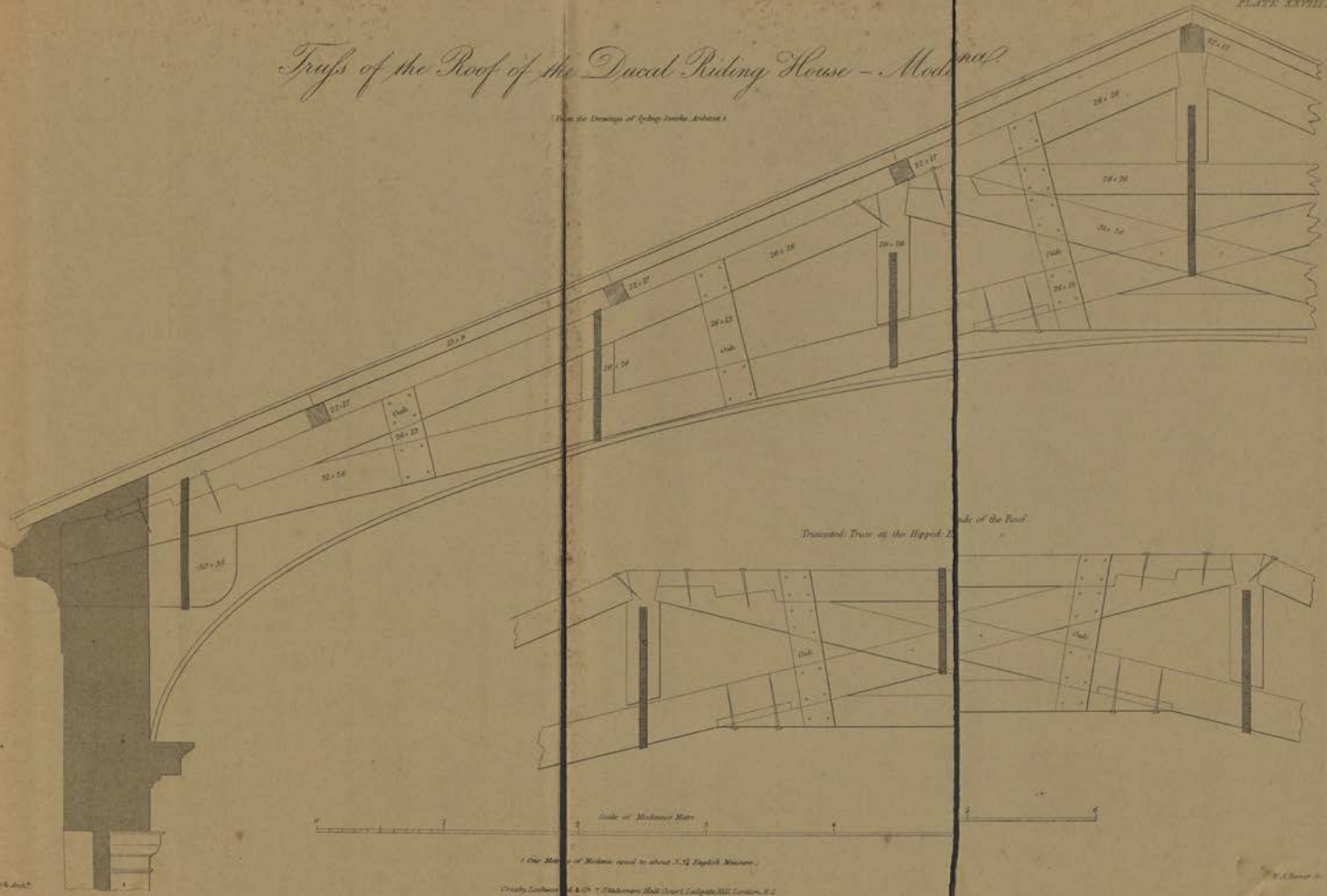


Crosby Lockwood & Co. Stationers Hall Court Ludgate Hill London, E.C.

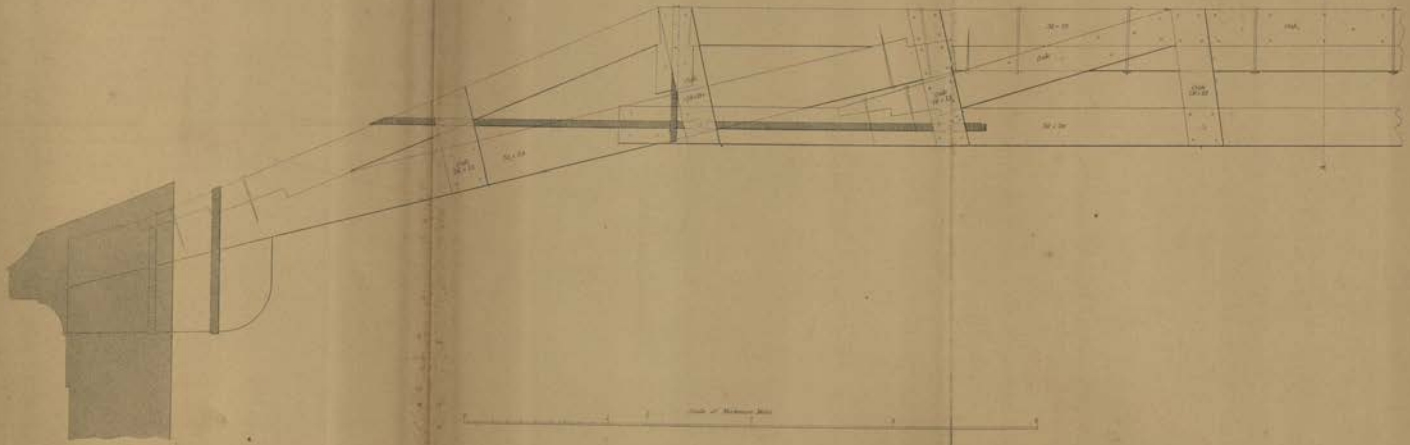
W. A. Bowser, Sc.

Truss of the Roof of the Ducal Riding House – Modena

From the Drawings of Sydney Smirke Architect


Oak
Oak
Oak

Framed Trusses of the Roof of the Ducal Palace, Modena.



Truss of Roof over the Public Riding House — Modena.

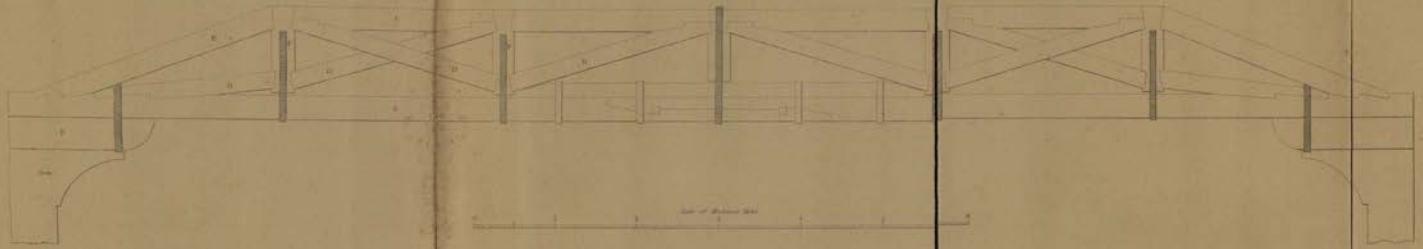
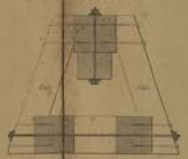
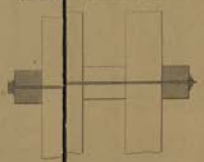
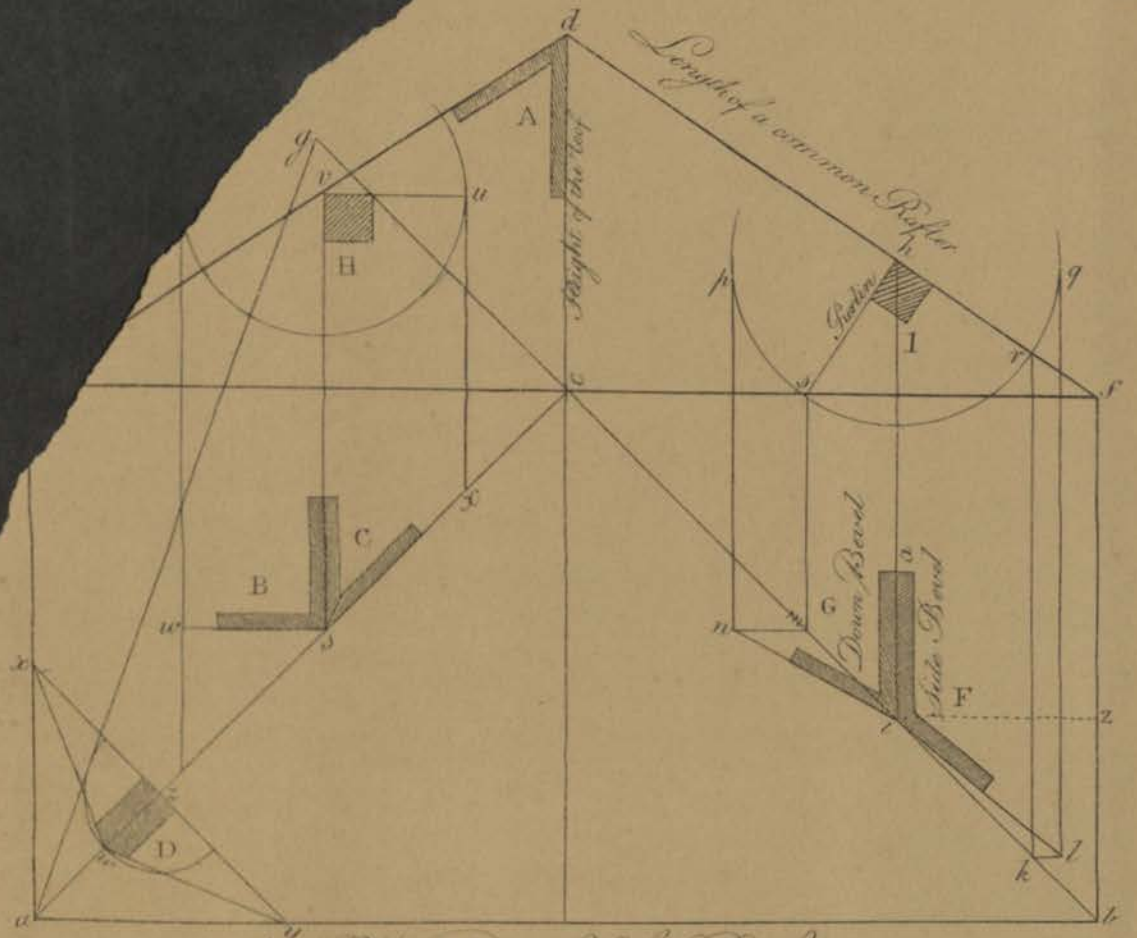


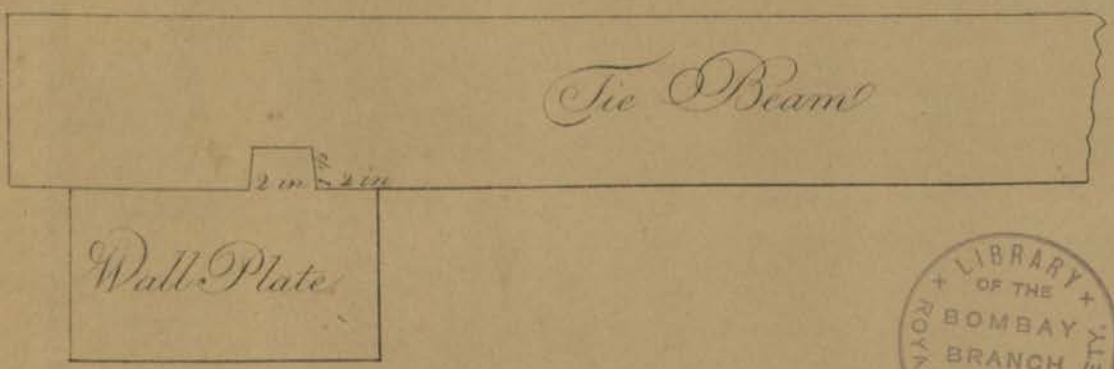
TABLE OF SCANTLINGS

A	15 × 30	Scale Miles
B	40"	40"
C	30"	30"
D	30 × 27	30"
E	30 × 24	30"
F	27 × 19	30"









LIBRARY OF THE BOMBAY BRANCH OF THE ROYAL ASIATIC SOCIETY

Crosby Lockwood & Co.ª 7 Stationers' Hall Court, Ludgate Hill, London, E.C.

Domes.

Fig. 1.

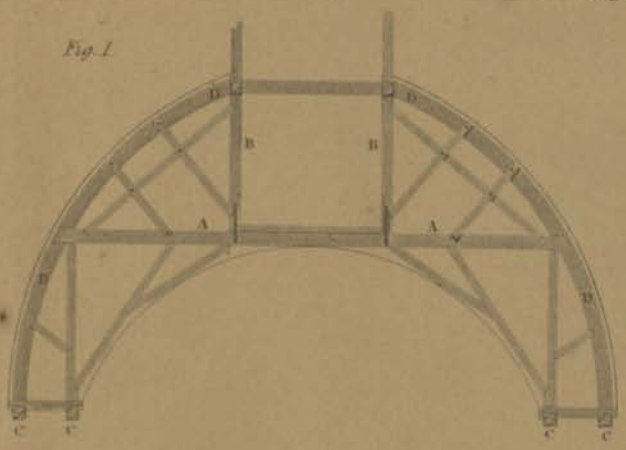


Fig. 2.

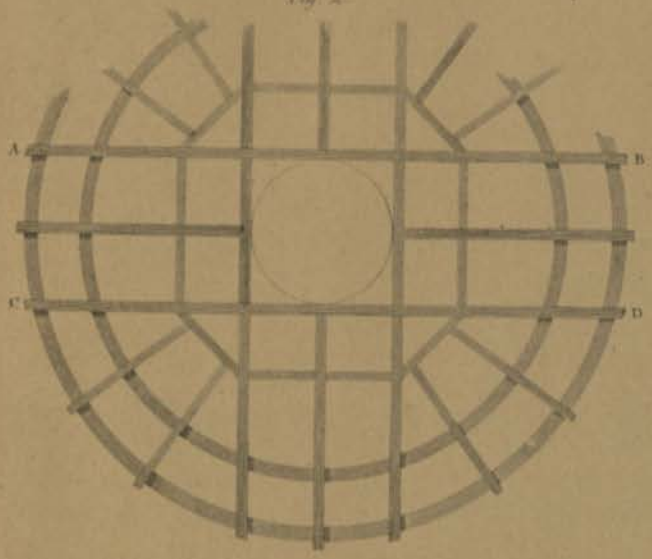


Fig. 3.

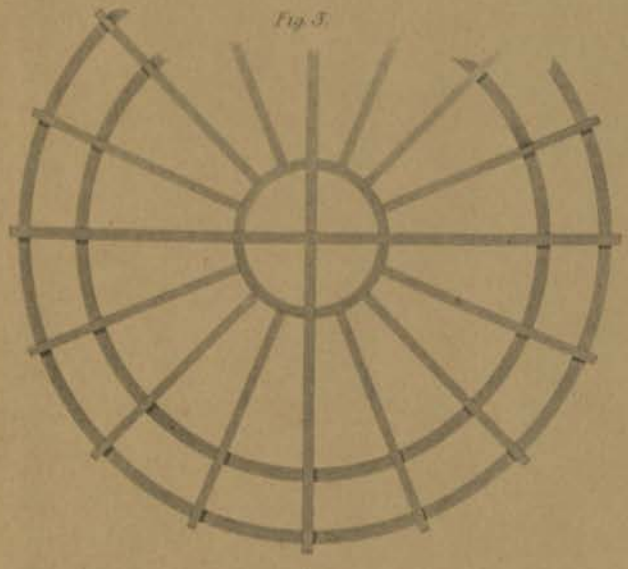


Fig. 4.

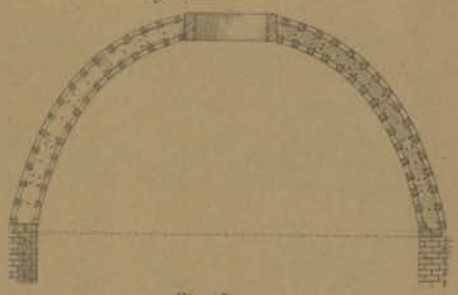


Fig. 5.

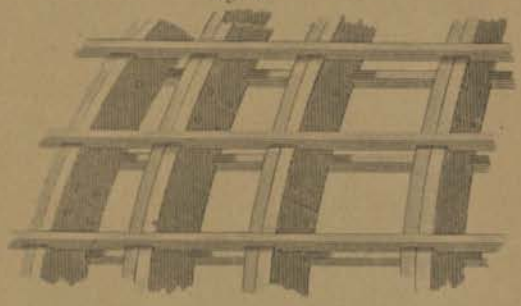


Fig. 6.

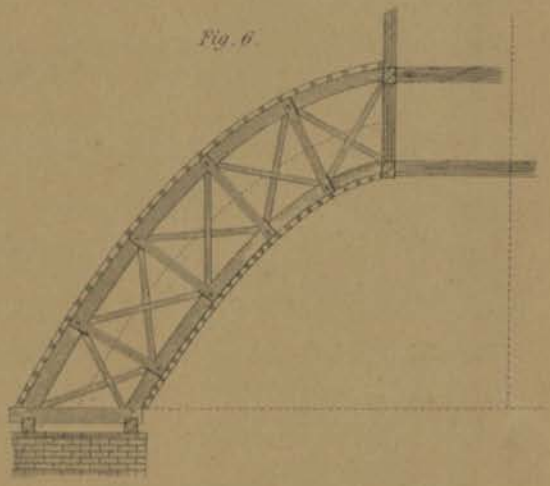
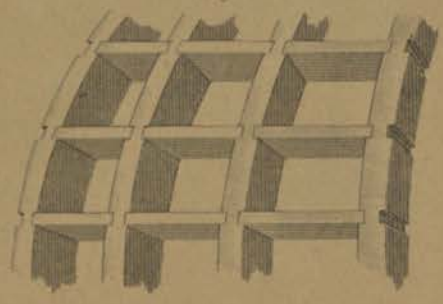


Fig. 7.



Drawn by R. Dodgild.

Engraved by James Basire.

Pub.d by Lockwood & Co 7. Stationers Hall Court Ludgate Hill London E.C.

Partitions and Centres.

PLATE XXXIII.

Fig. 1.

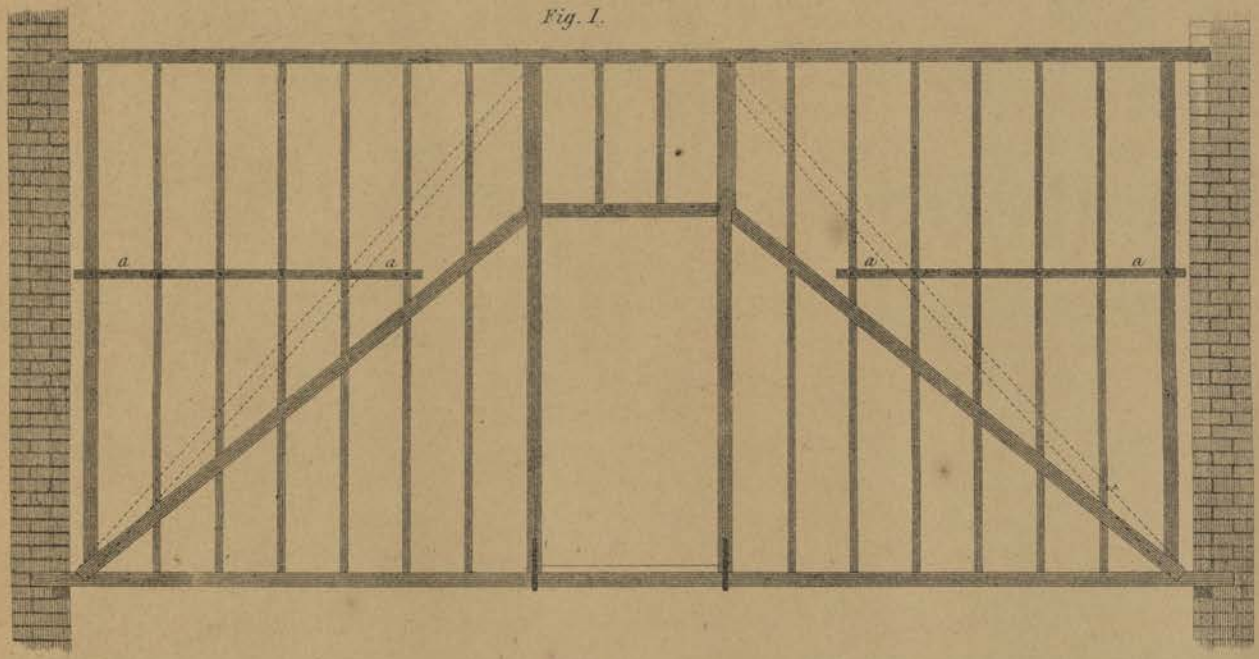
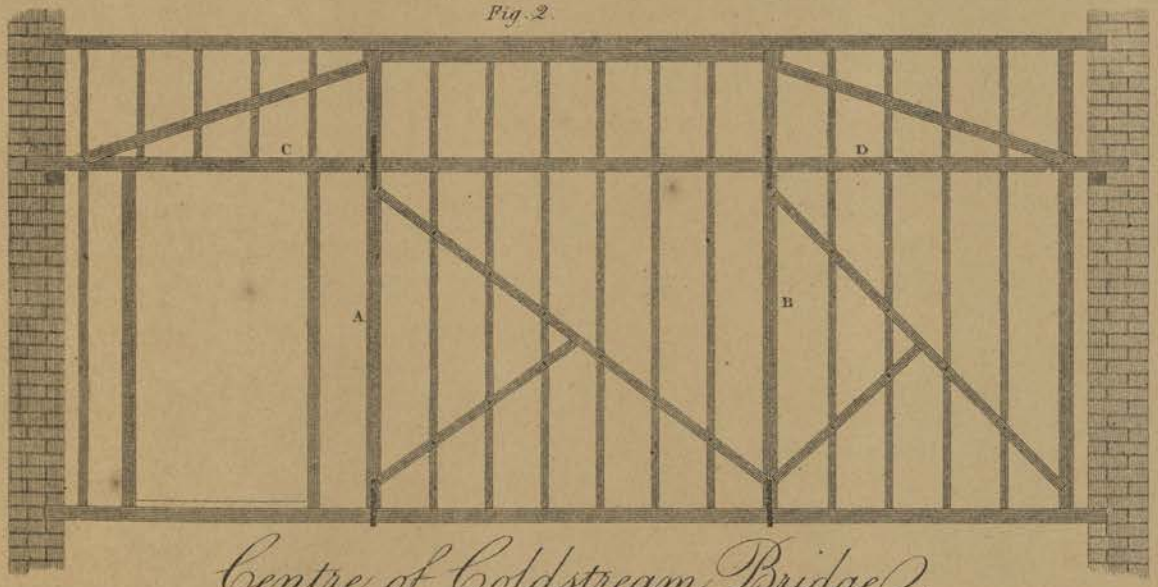
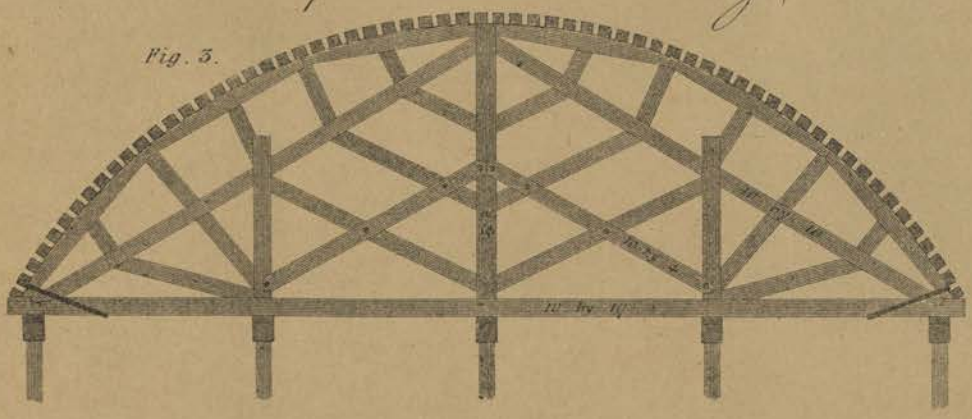


Fig. 2.



Centre of Coldstream Bridge.

Fig. 3.



Drawn by R. Tredgold.

Crosby Lockwood & Co.ª 7, Stationers' Hall Court, Ludgate Hill, London. E.C.

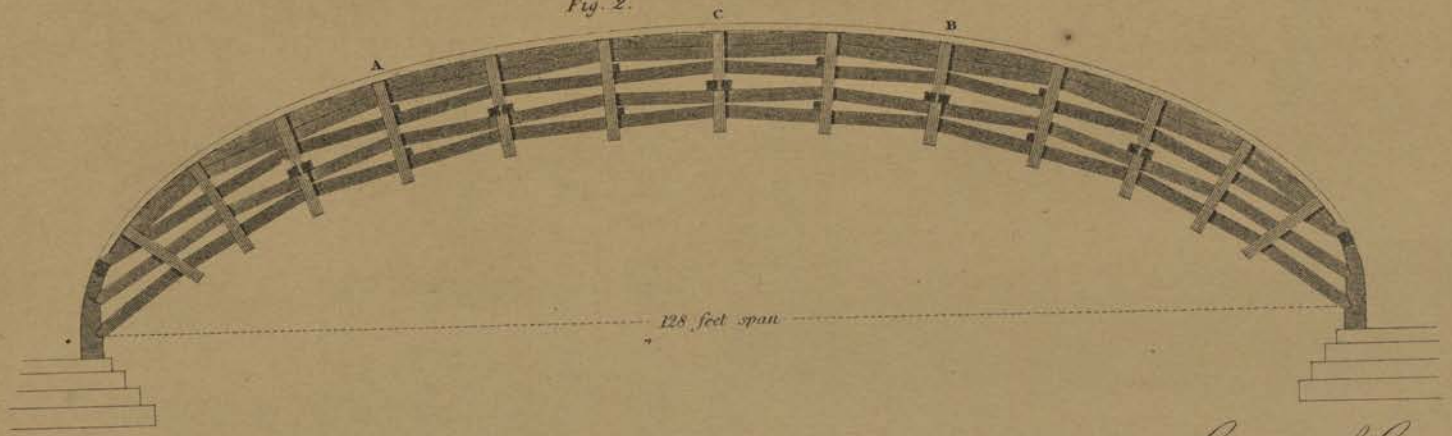
Engraved by James Davis.

Centres for Stone Bridges.

PLATE XXXIV.

The Centre used for the Bridge at Neuilly.

Fig. 2.

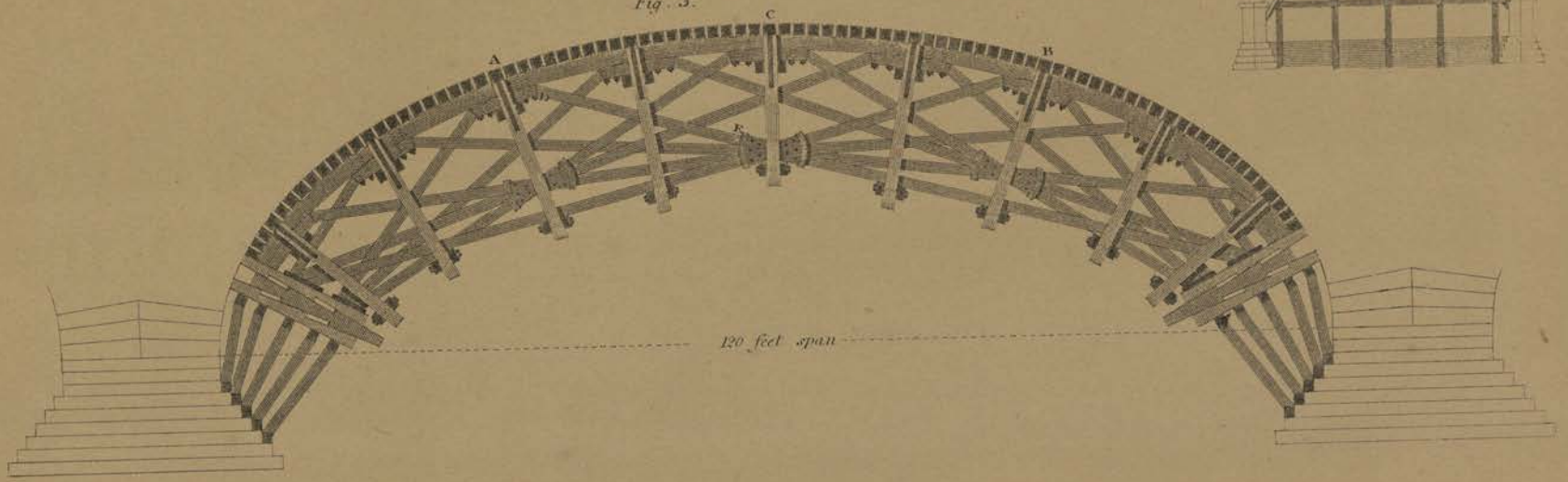


Centre of Conon Bridge.

Fig. 1.

The Centre used for the Waterloo Bridge.

Fig. 3.



Engraved by James Havir

Drawn by R. Trolgold.

Crosby Lockwood & Co 7 Stationers' Hall Court, Ludgate Hill, London, E.C.

Centres for Stone Bridges.

PLATE XXXV.

N° II.

Fig. 1.

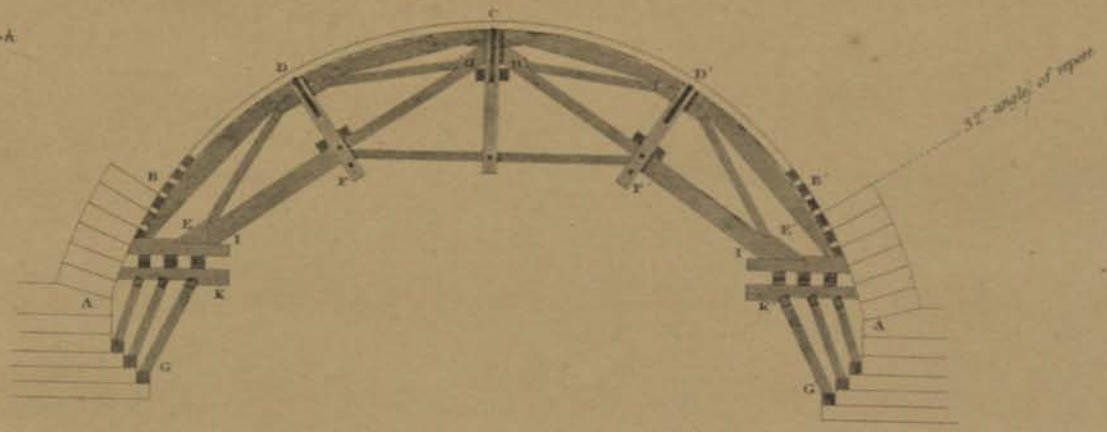
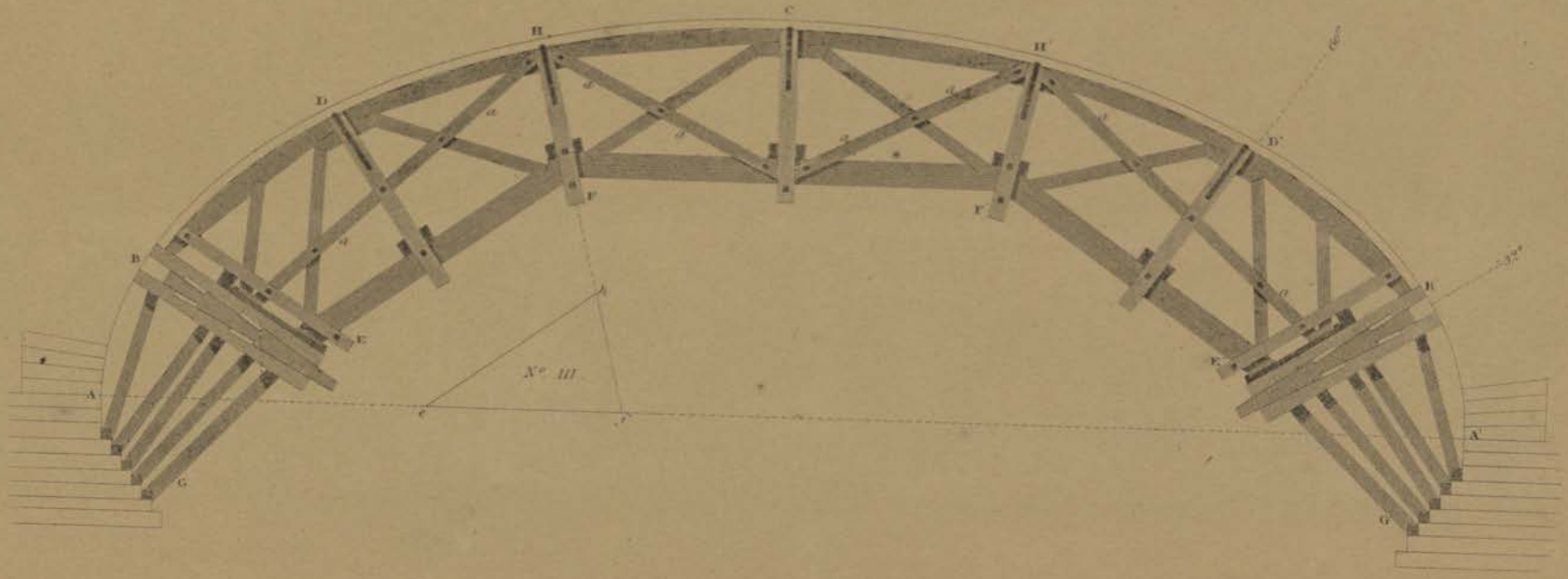


Fig. 2.



Drawn by R. Tredg.

Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill, London, E.C.

Engraved by James Davis.

Bridges.

PLATE XXXVI.

Fig. 1.

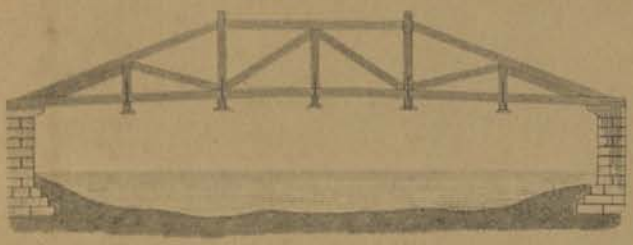


Fig. 2.

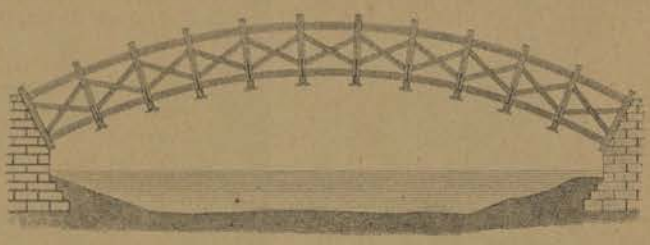


Fig. 3. Bridge over the Brenta.

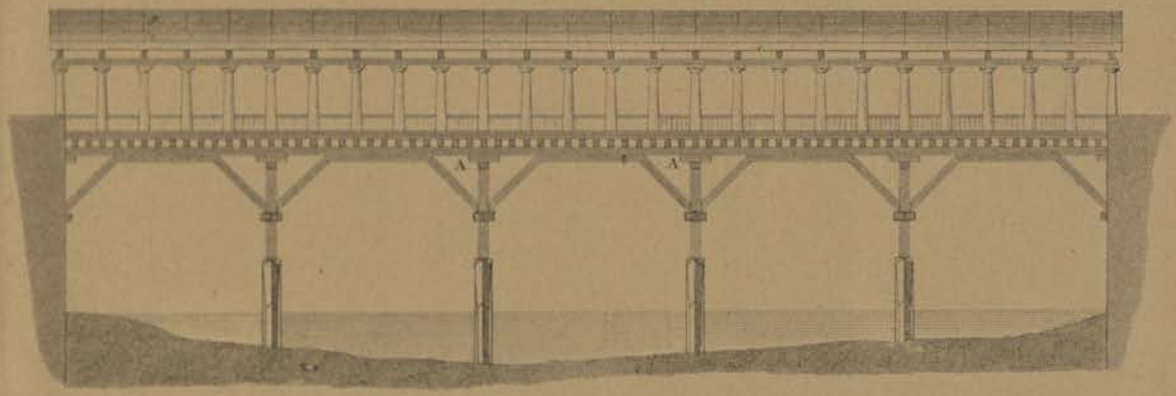


Fig. 4. American bridge

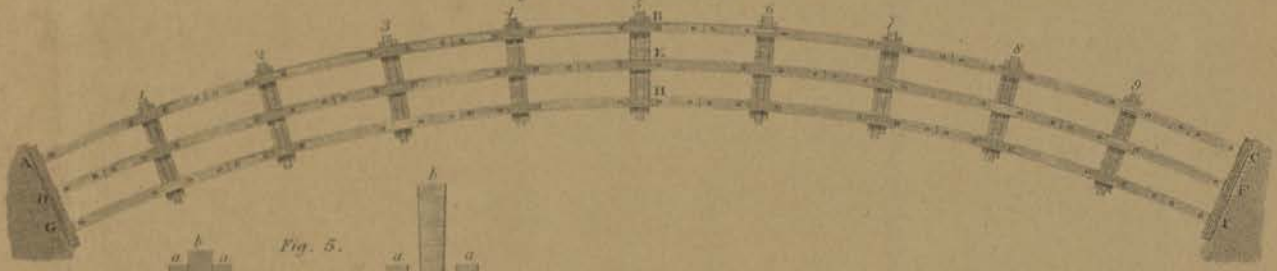


Fig. 5.

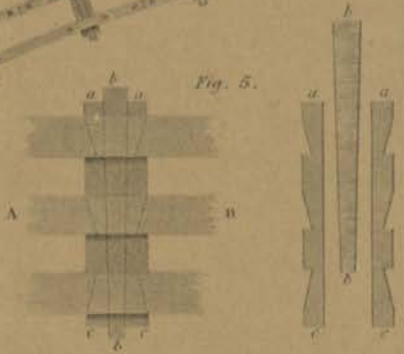
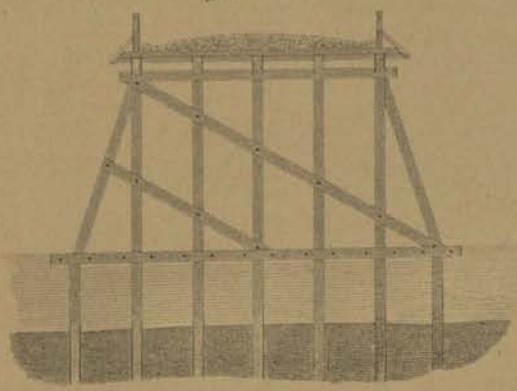


Fig. 6.

Fig. 7.

Fig. 8.



Drawn by F. Tindsold

Engraved by James Davis

Crosby Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill London E.C.

Bridges.

PLATE XXXVII.

Fig. 1. Freysingen Bridge, over the Isar.

Fig. 3. Bridge of Bamberg.

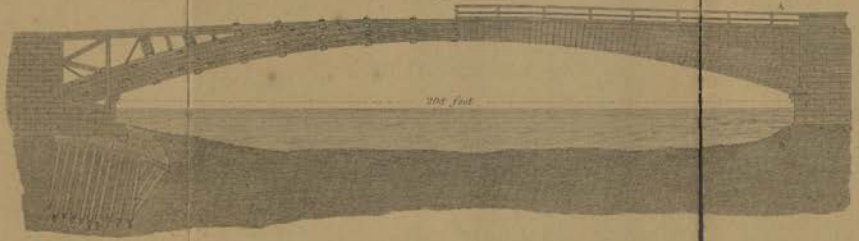


Fig. 5.

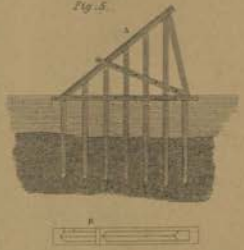


Fig. 2.

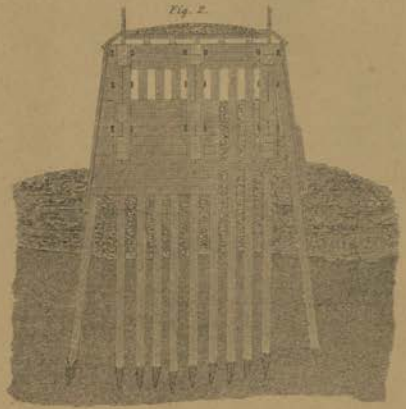


Fig. 4.

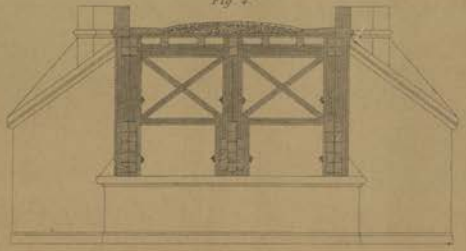
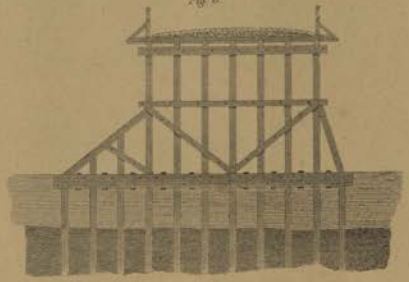


Fig. 6.



Drawn by R. Dickson.

Crosby Lockwood & Co. 7, Stationers' Hall Court, Ludgate Hill, London, E.C.

Engraved by James Davis.

Construction of Bridges.

PLATE XXXVIII.

Fig. 1.

Fig. 2.

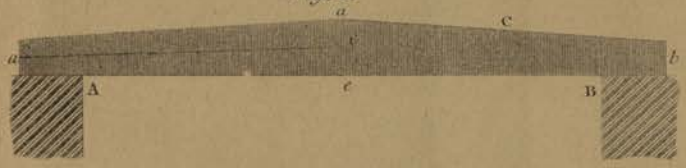


Fig. 3.

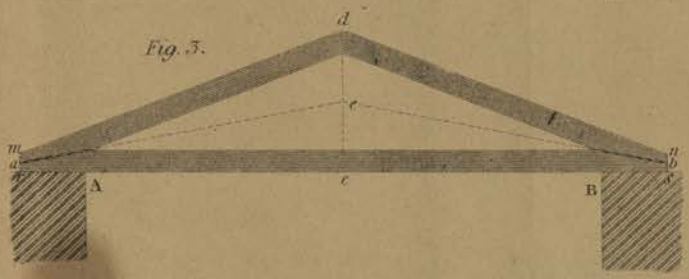


Fig. 4

Fig. 5.

Fig. 6.

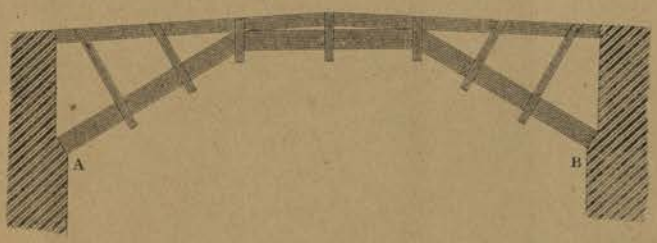


Fig. 7.

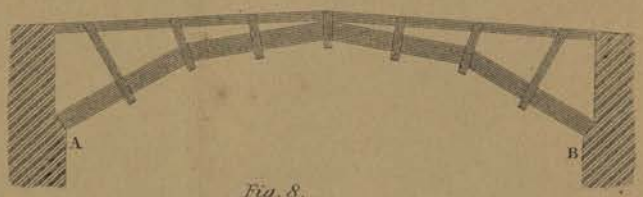


Fig. 8.

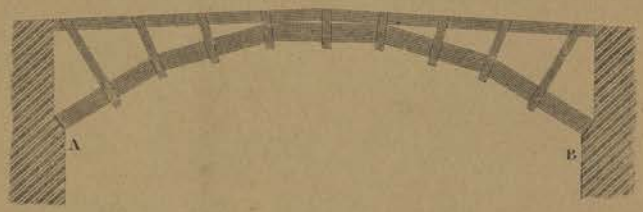


Fig. 9.

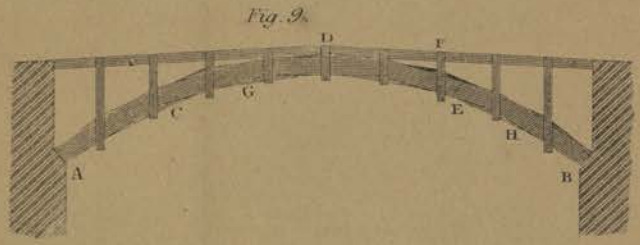


Fig. 10.

Fig. 11.

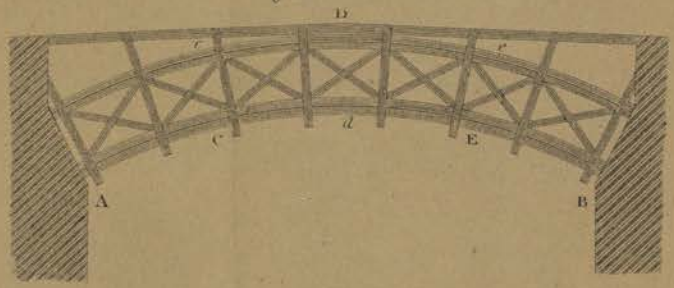
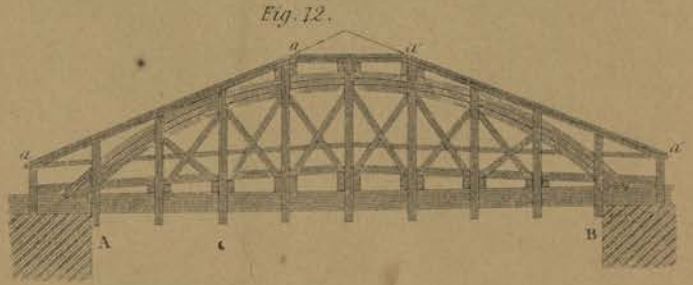


Fig. 12.



Drawn by R. Tredgold.

Engraved by James Davis.

Crosby Lockwood & Co 7 Stationers Hall Court Ludgate Hill London E.C.

Bridges.

PLATE XXXIX.

Fig. 2.

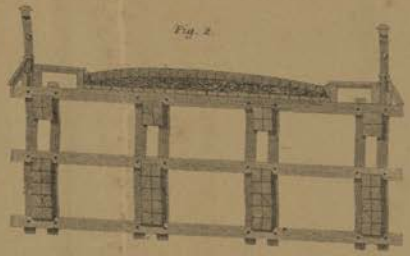


Fig. 1.

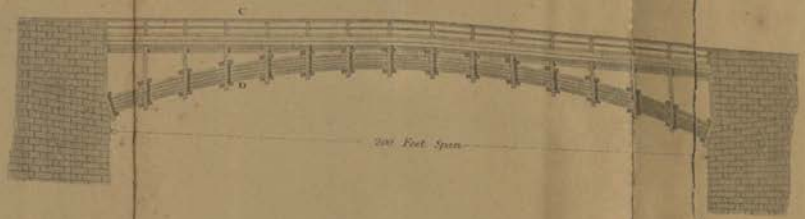


Fig. 3.

Fig. 5.

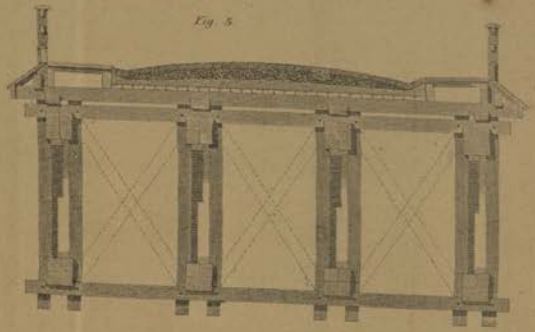
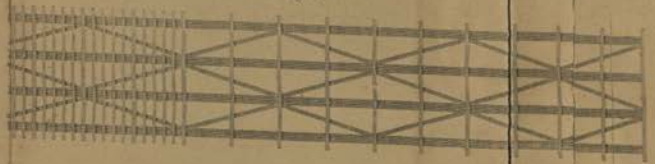


Fig. 4.



Drawn by B. Tredgold.

Drawn by Lockwood & Co. 7 Stationers Hall Court Ludgate Hill London E.C.

Engraved by James Davis.

PLAN ELEVATION AND DETAILS OF AN OCCUPATION BRIDGE.

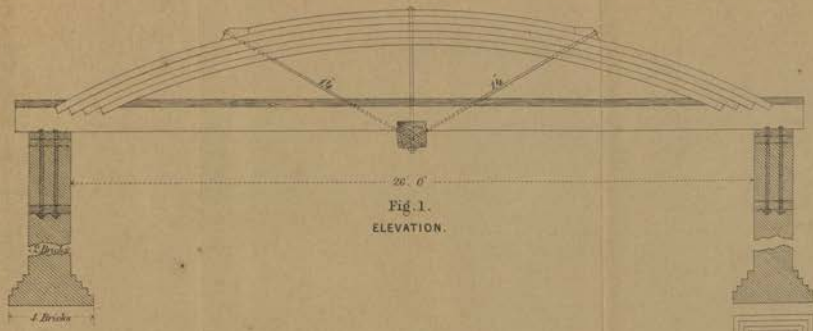


Fig. 1.
ELEVATION.

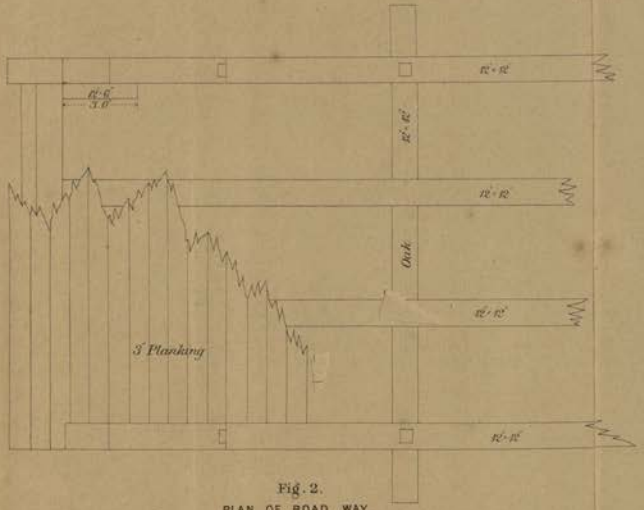


Fig. 2.
PLAN OF ROAD WAY.

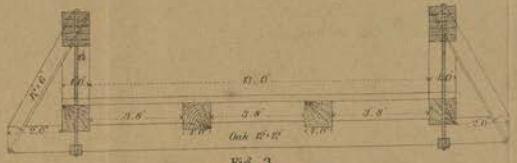


Fig. 3.
TRANSVERSE SECTION.

Fig. 4.

PLAN OF PIER.

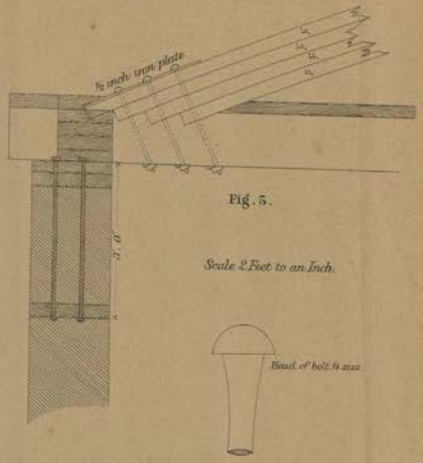


Fig. 5.

DETAILS OF HOLDFAST BOLTS.

Fig. 6.

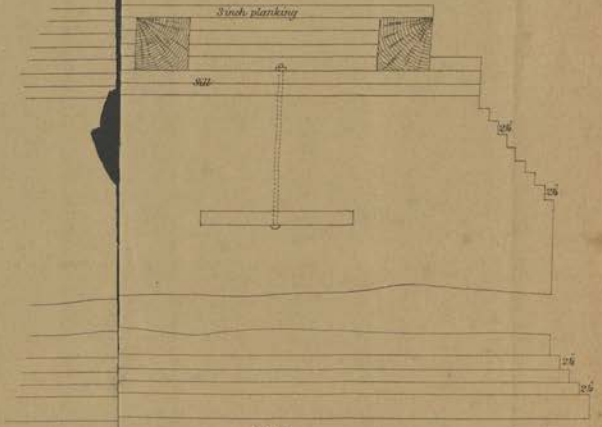


Fig. 6.
PART ELEVATION OF PIER.

W. Barnhart Del.

Crosby Lockwood & Co 7 Stationers' Hall Court, Ludgate Hill.

Town's Patent Lattice Bridge.

Fig. 1.

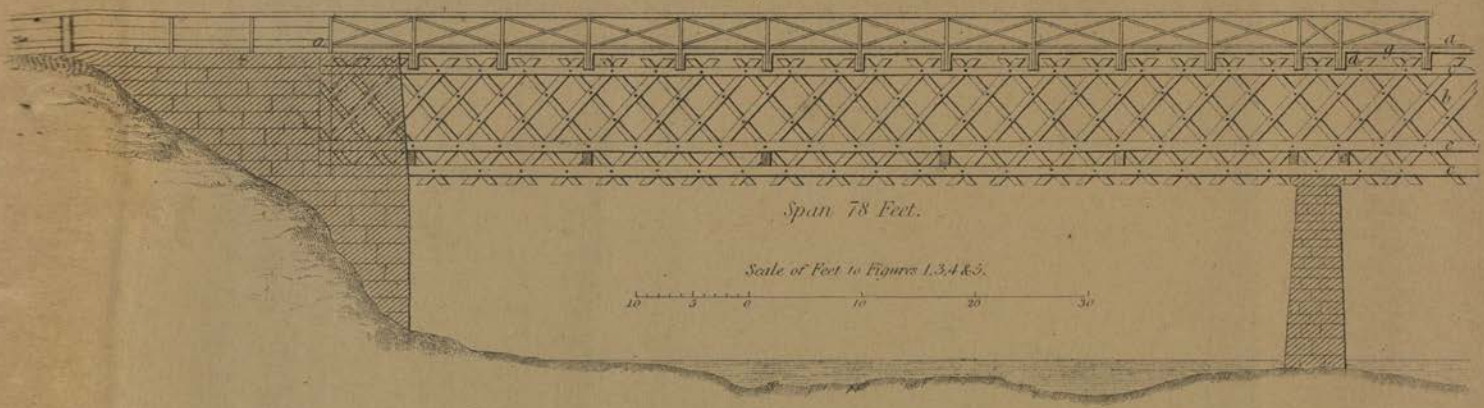


Fig. 2.

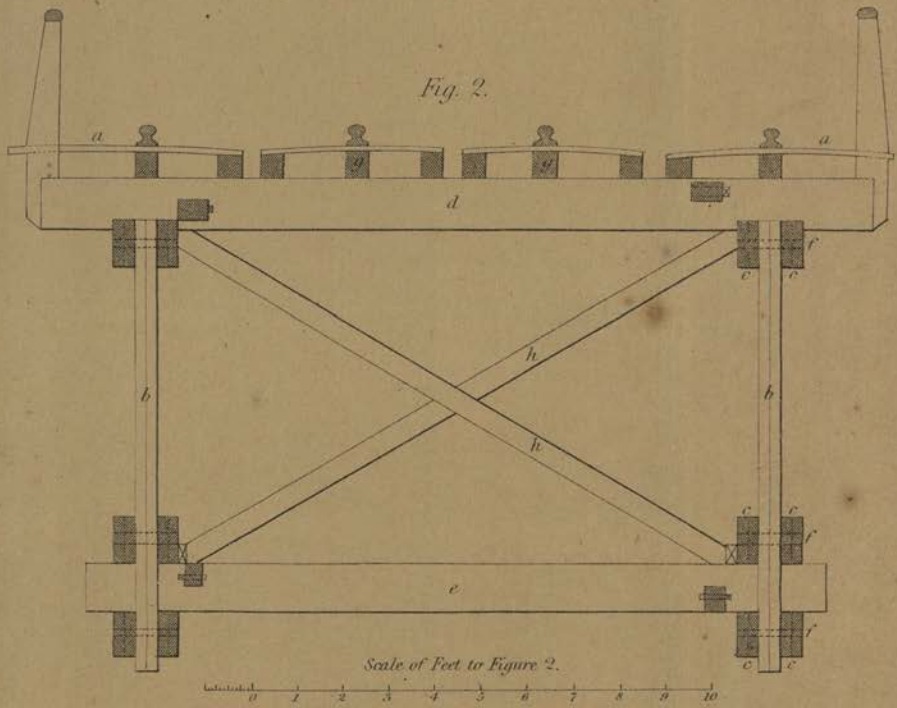


Fig. 5.

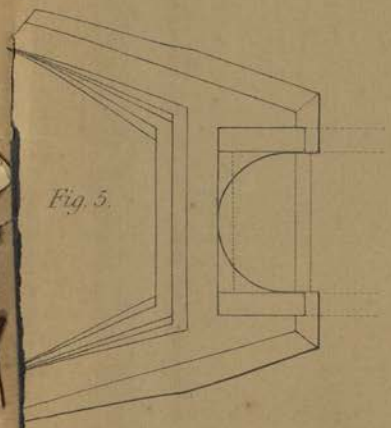


Fig. 4.

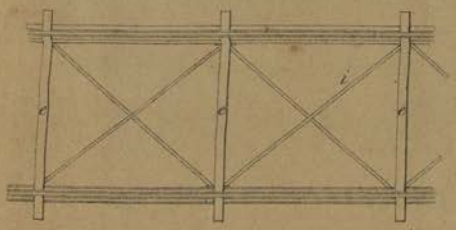
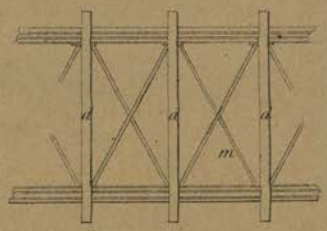


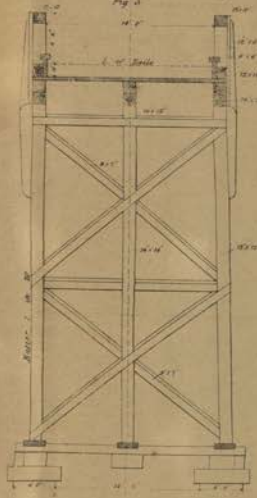
Fig. 3.



Crosby Lockwood & Co.ª 7, Stationers Hall Court, Ludgate Hill, London, E.C.

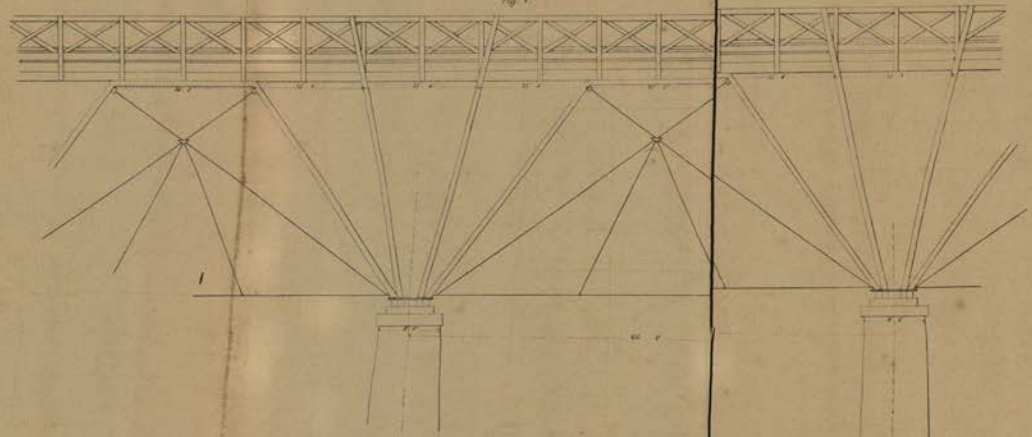
Geo. Aikman, Sculp.

Enlarged Transverse Section of Superstructure
Fig 3

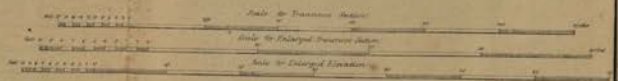


COLLEGE WOOD VIADUCT.

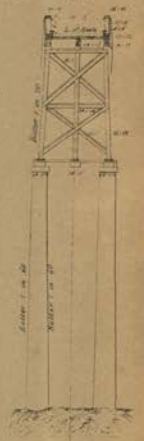
ELEVATION OF SUPERSTRUCTURE
Fig 1.



Scales.



Transverse Section
Fig 2.



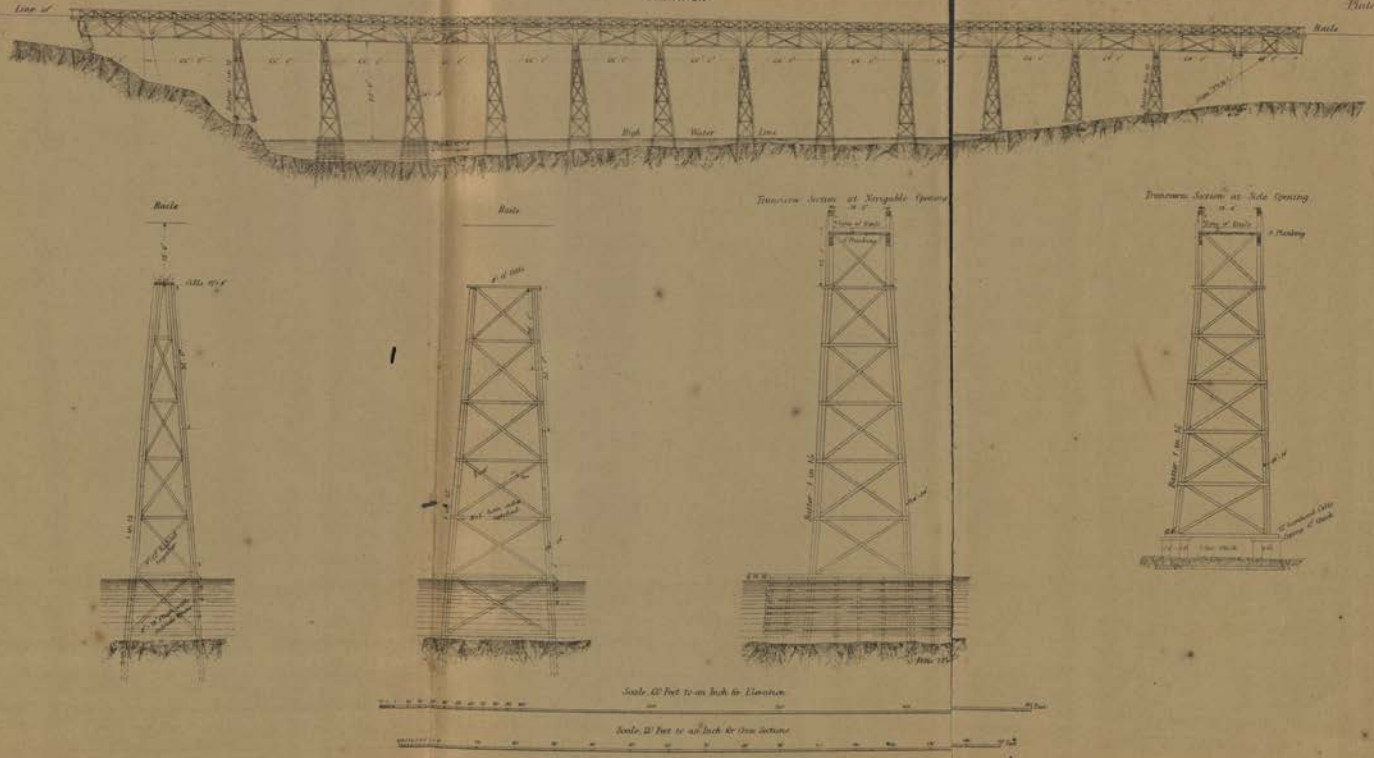
W. Barden del.

Printed by Lockwood & Co. 7, Stationers' Hall Court, Ludgate Hill.

ST GERMANS VIADUCT.

ELEVATION

Plate XLIII.

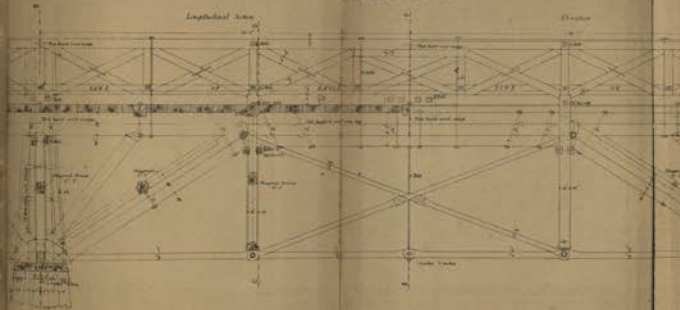


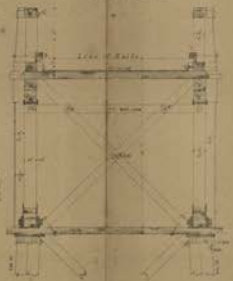
W. Hawkes, Sc.

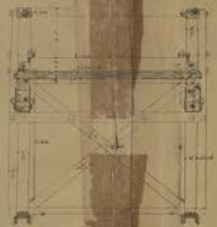
Crosby, Lockwood & Co. 7, Stationers Hall Court, Ludgate Hill.

DETAILS OF TRUSS

ST GERMANS VIADUCT.







Bridges and Joints.

Fig. 1.

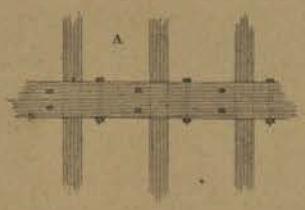


Fig. 2.

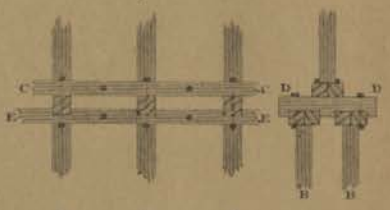
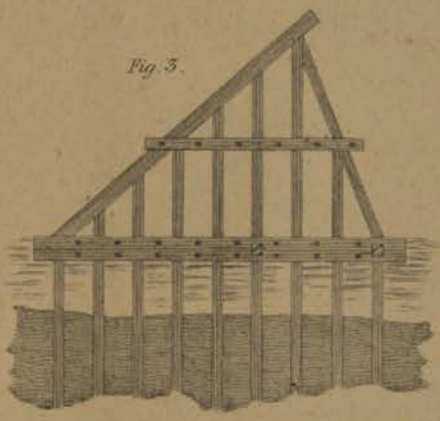


Fig. 3.



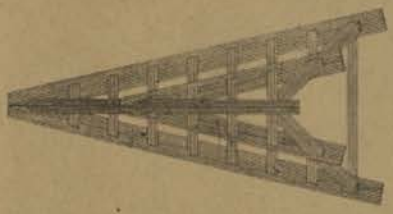


Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9

Fig. 10

Fig. 11.

Fig. 12.

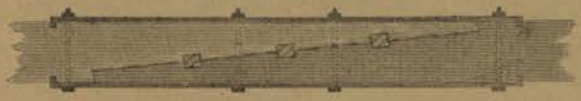


Fig. 13.

Drawn by F. Tredgold.

Engraved by James Davis

Crosby Lockwood & Co.ª 7, Stationers Hall Court, Ludgate Hill, London, E.C.

Joints.

PLATE XLVI.

Fig. 1.

Fig. 2.

Fig. 3.

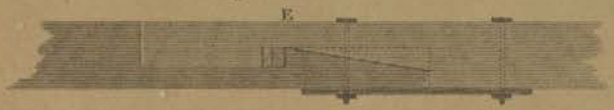


Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

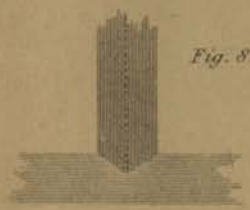


Fig. 10.

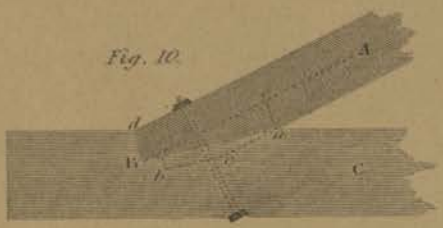


Fig. 11.

Fig. 9.

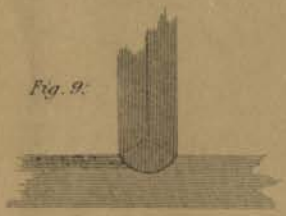


Fig. 14.

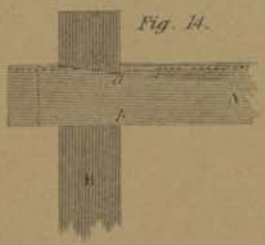


Fig. 12.

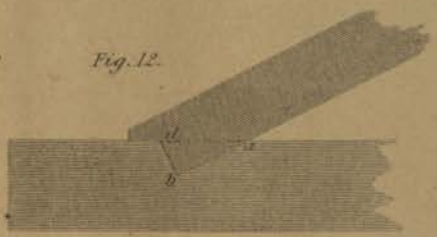
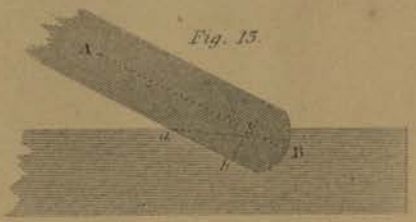


Fig. 13.



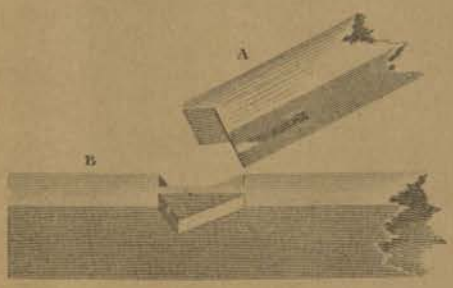
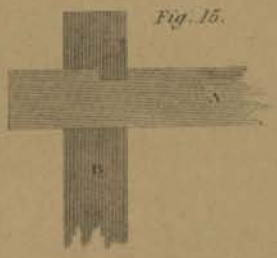
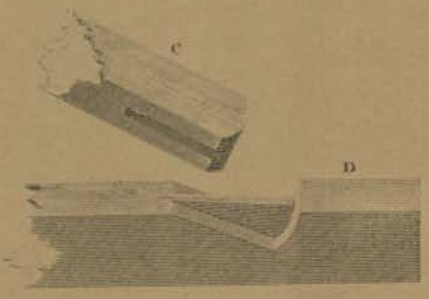


Fig. 15.





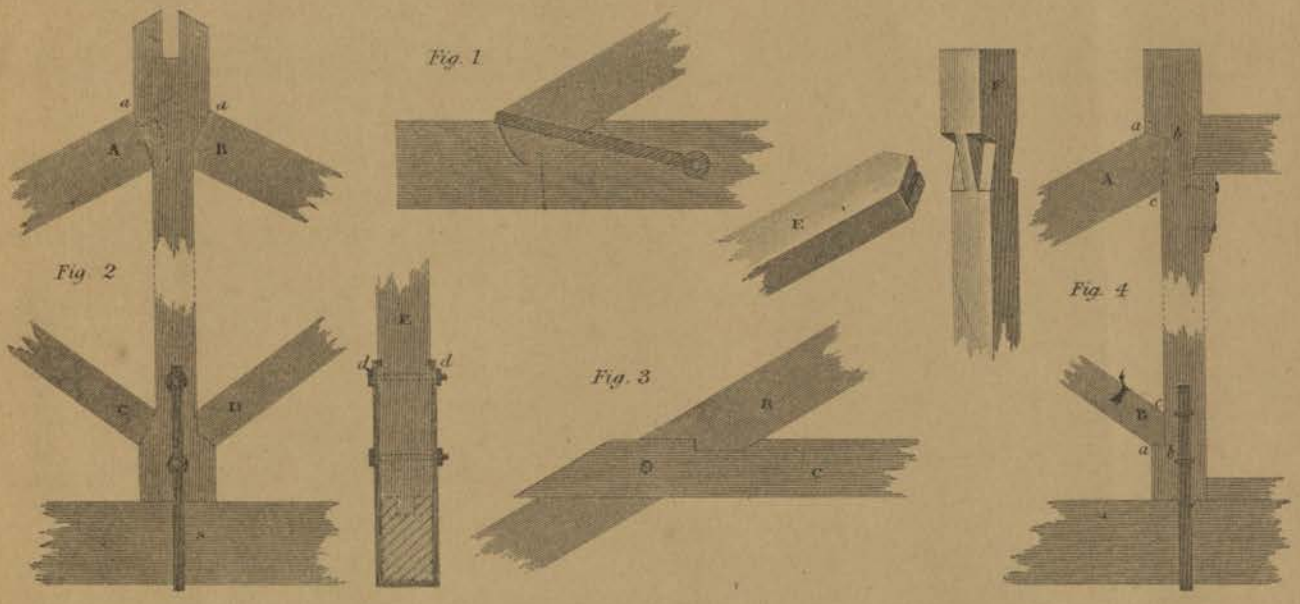
Drawn by R. Tredgold

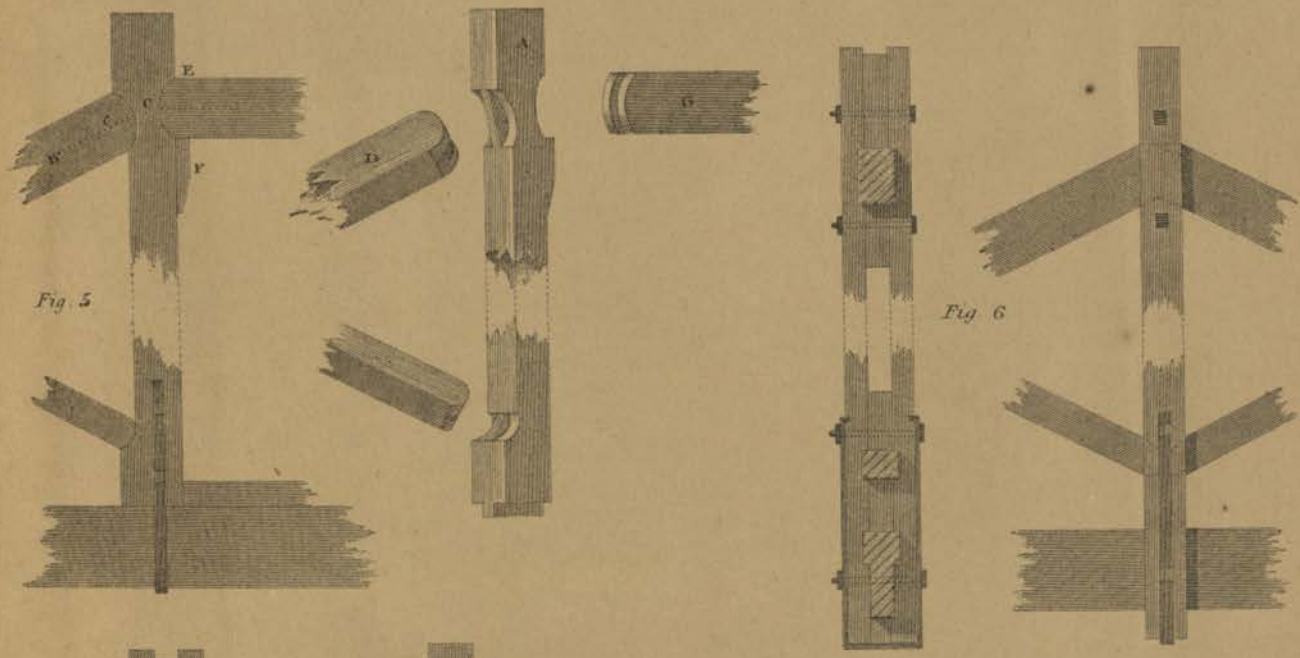
Crosby Lockwood & Co. 7, Stationers Hall Court Ludgate Hill, London E.C.

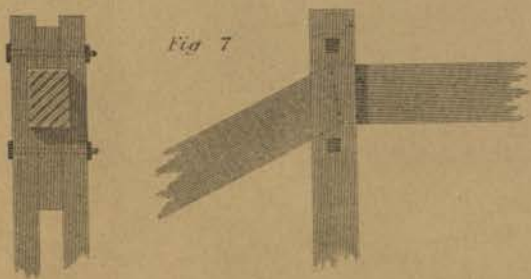
Engraved by James Davis

Joints and Straps.

PLATE XLVII.







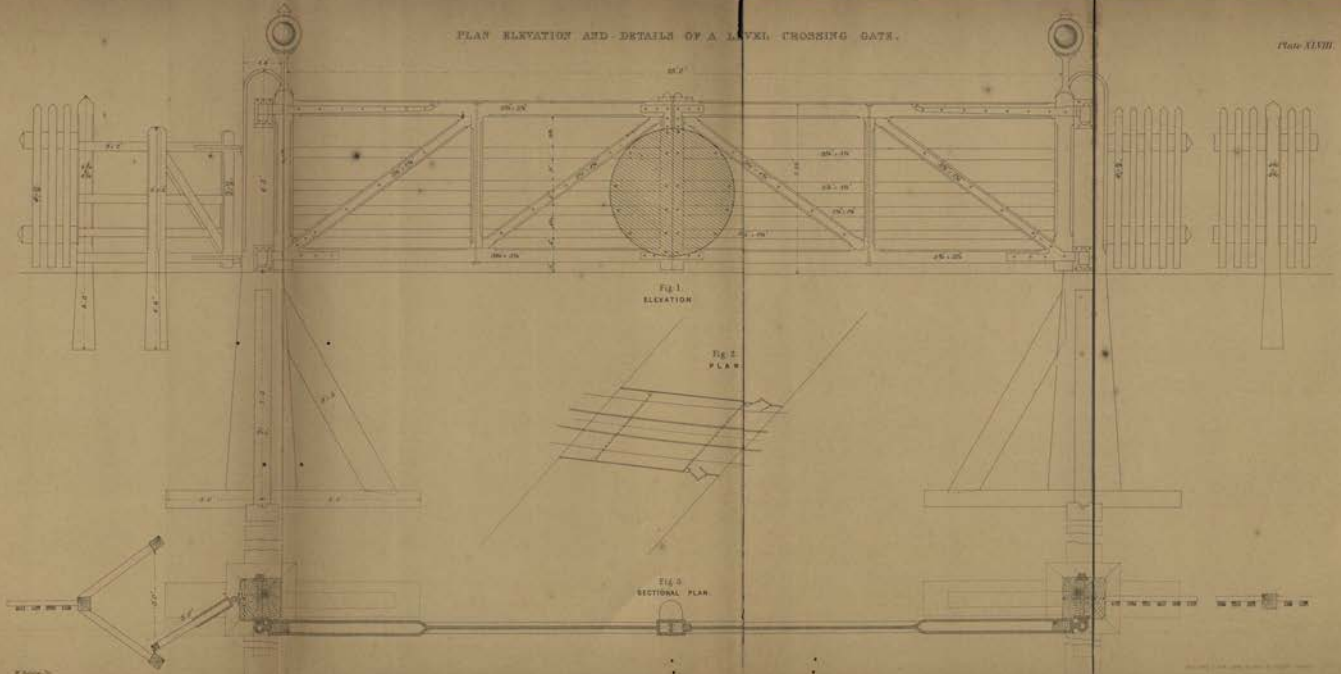
Drawn by R. Tredgold.

Crosby Lockwood & Co.ª 7 Stationers Hall Court, Ludgate Hill, London, E.C.

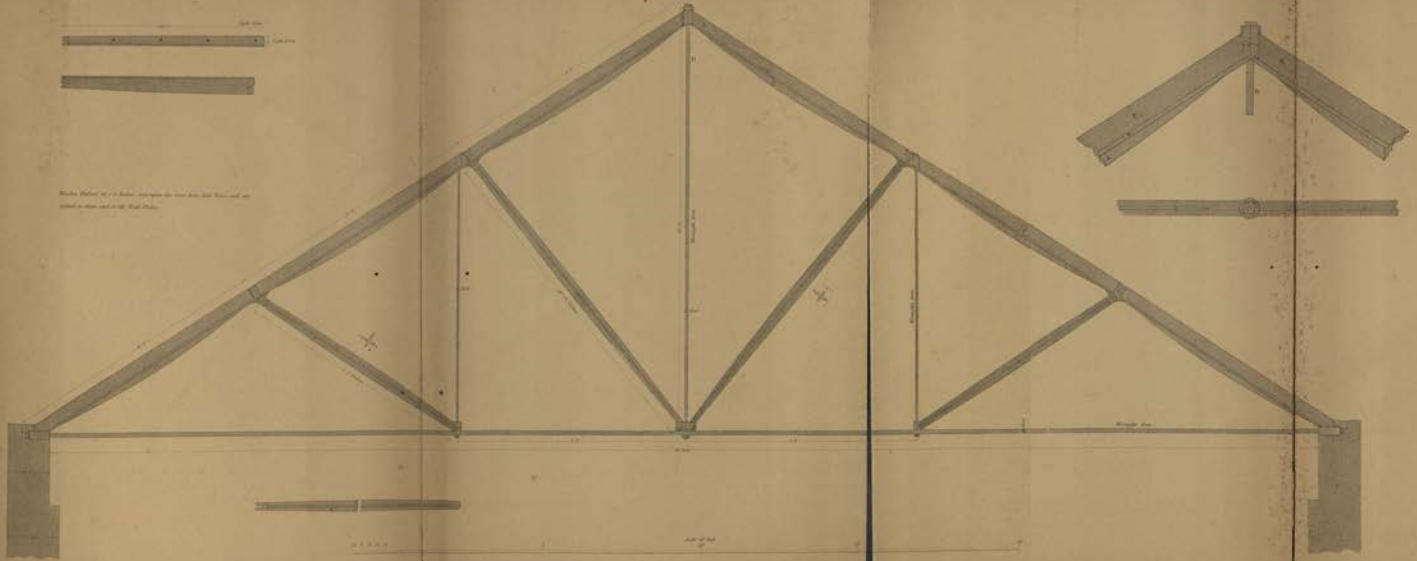
Engraved by James Davis.

PLAN ELEVATION AND DETAILS OF A LEVEL CROSSING GATE.

Plate XLVIII.



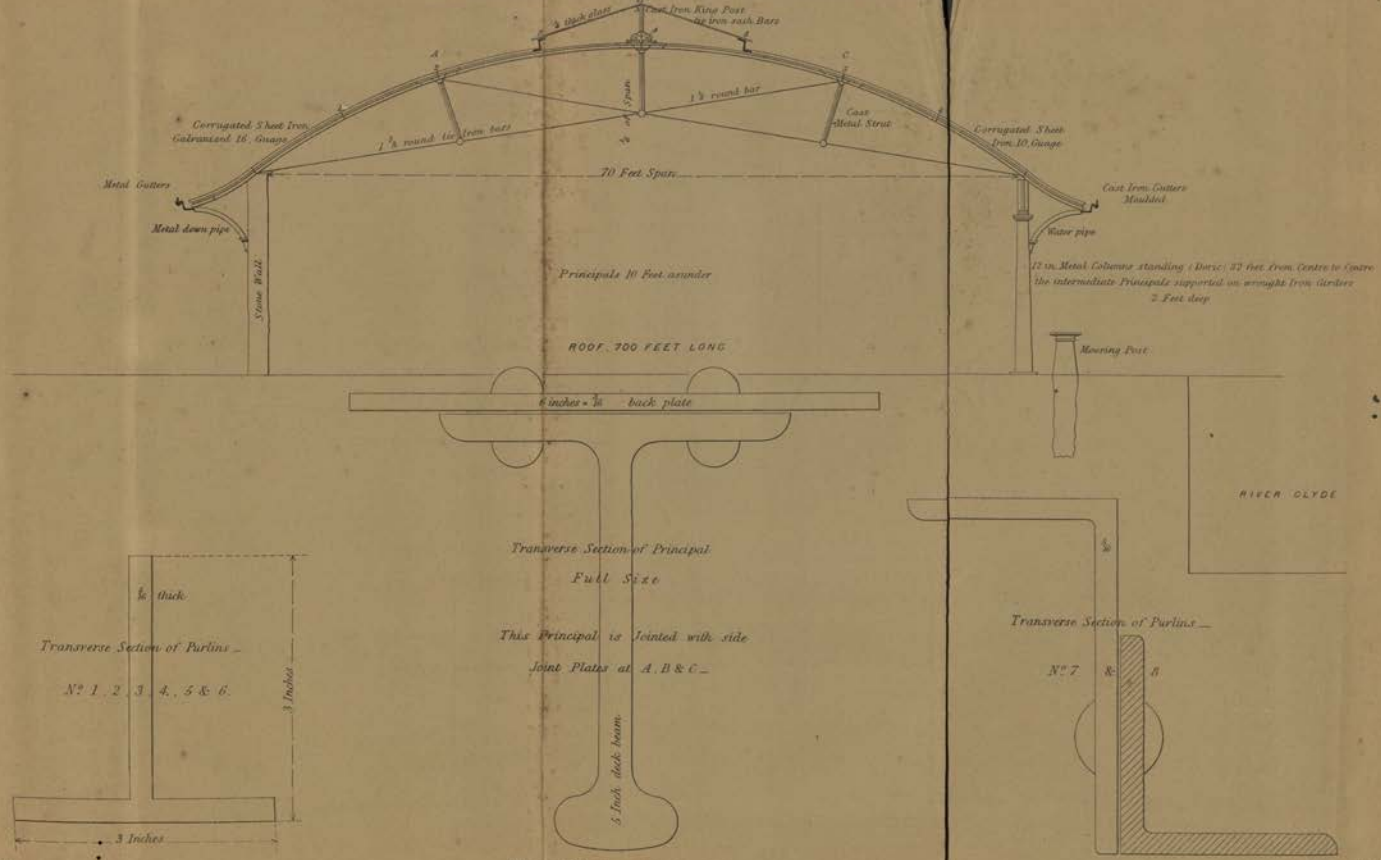
Roof over the Smithery at Butterley Iron Works



IRON ROOF.

MADE FOR THE CLYDE TRUSTEES FOR THE QUAY AT GLASGOW.

Plate L.



Wich^d Turner del.

Crosby Lockwood & Co. 7 Stationers Hall Court Ludgate Hill London E.C.

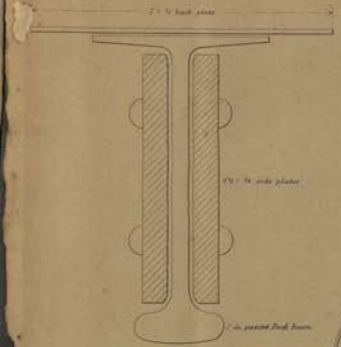
W. A. Brewer sc.

DETAIL No. OF IRON ROOF.

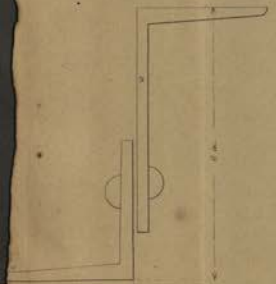
Plate LI.

ERECTED FOR MESS. JOSEPH WHITWORTH & Co.

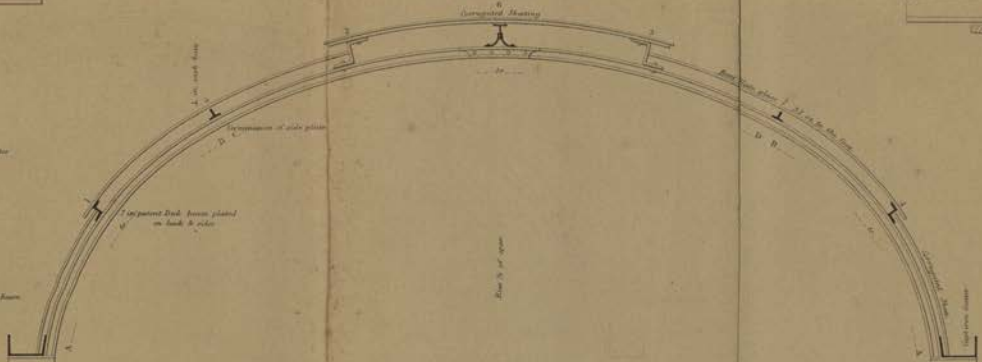
MANCHESTER.

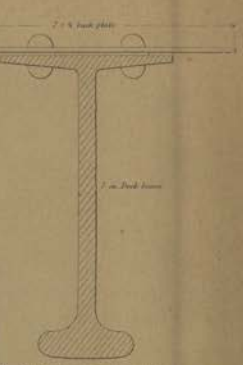


½ full size section of one fourth span each side from springing from A to B.

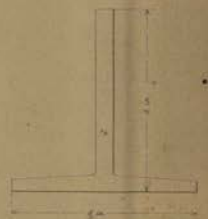


Transverse pattern of Purlins 1 2 3 & 4 Made of Angle iron.


Corrugated Sheeting
7 in. bark plate
Transverse of side plates
7 in. patent Bark bears plated on back & side
Roof 3 of span
Roof plate ¼ × 3 & 2½ × 2½ × ¼ Angle Iron
Gutter plate
40 feet span
three Principals, stand 15 feet from Centre to Centre.
Scale ¼ one foot
80 ft.
Roof 100 feet long



½ full size section of central half of Principal from C to D



Transverse Sections of Purlins 5 6 & 7 made of tee iron.

Richd. Turner del.

W. A. Brooks Sc.

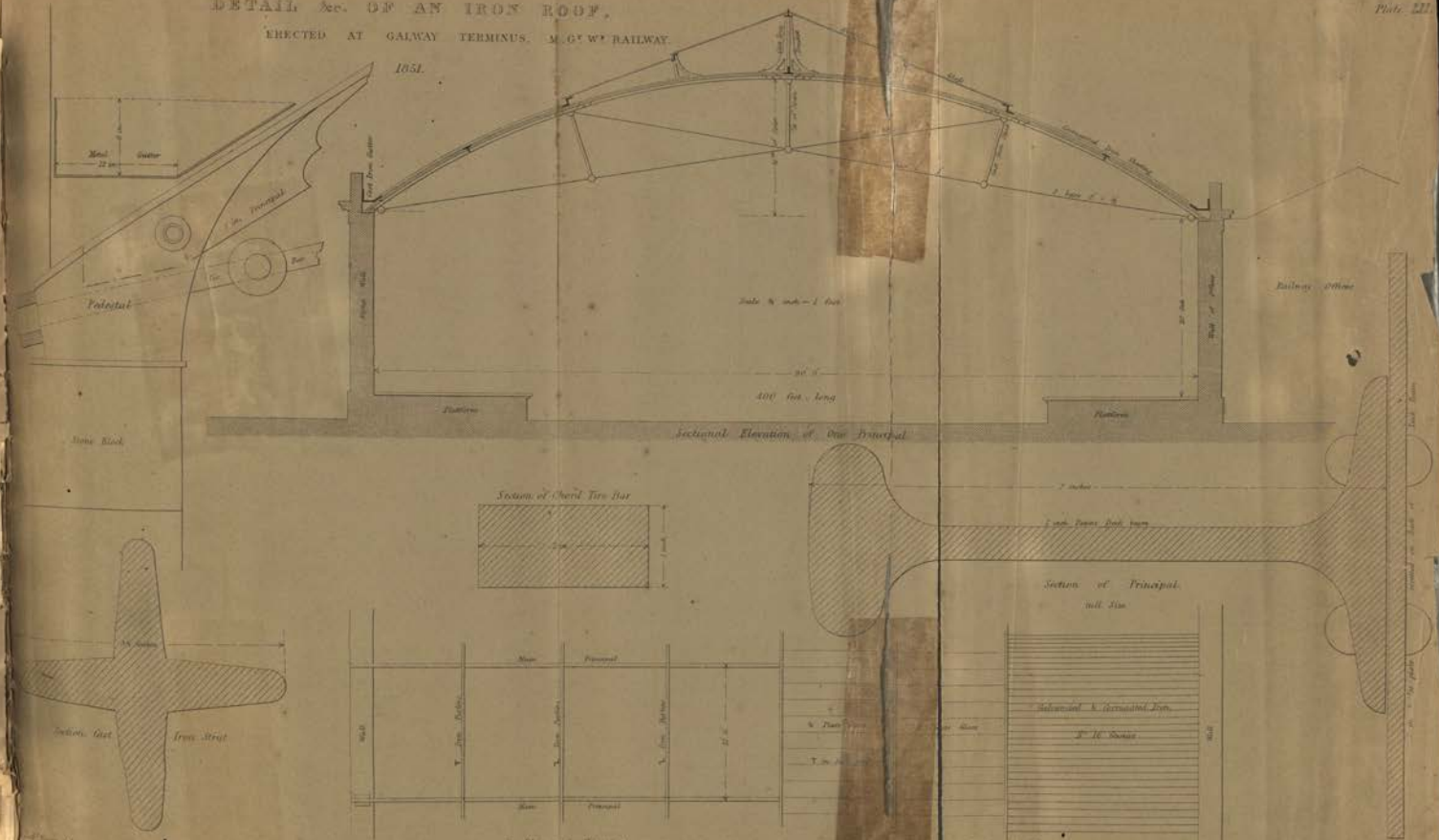
Crosby Lockwood & Co. 7 Stationers Hall Court Ludgate Hill London E.C.

DETAIL &c. OF AN IRON ROOF,

ERECTED AT GALWAY TERMINUS. M.G.W.R. RAILWAY.

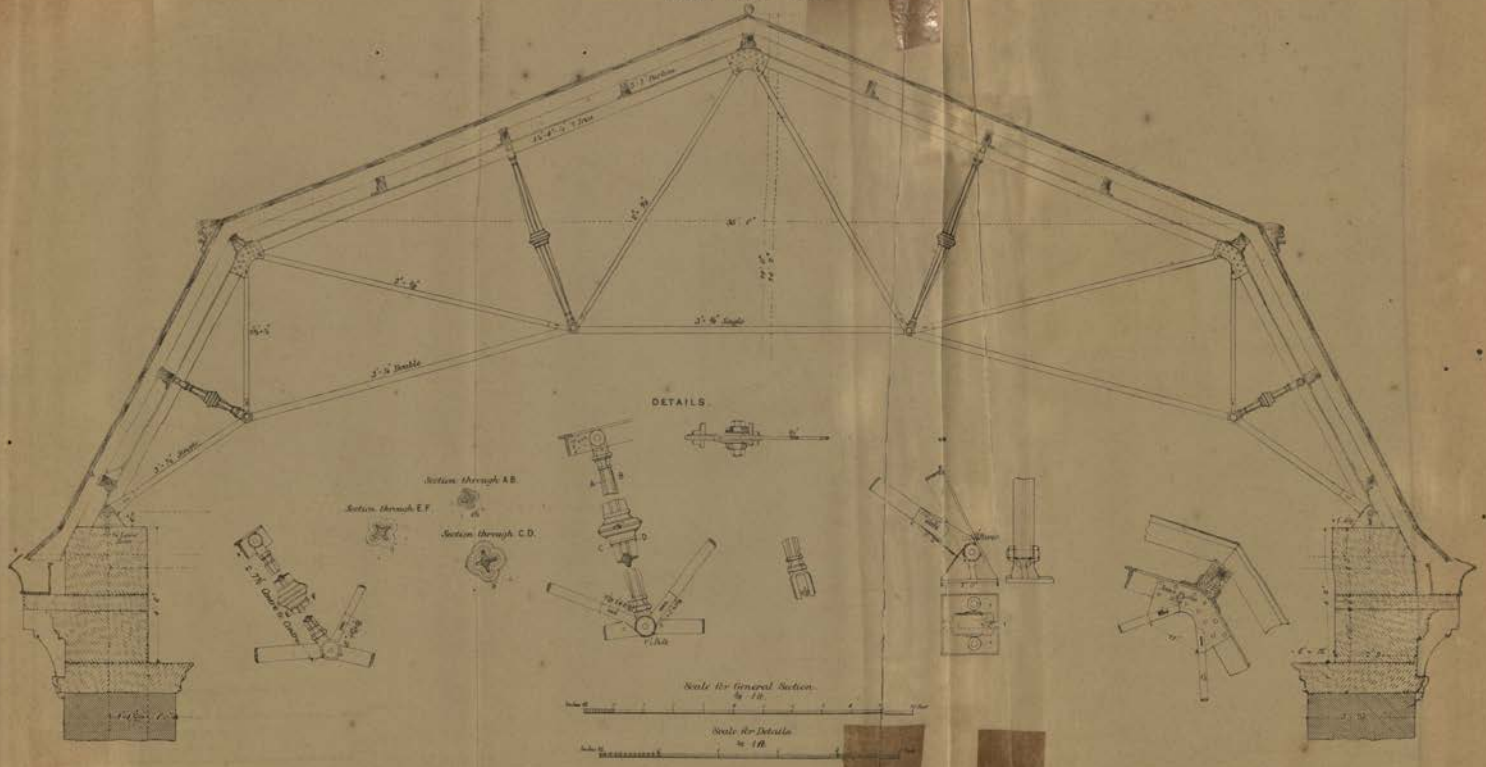
1851.

Plate XII



ABBEY MILLS PUMPING STATION

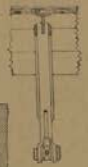
ENGINE HOUSE ROOF.

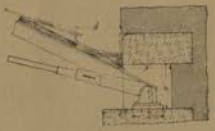


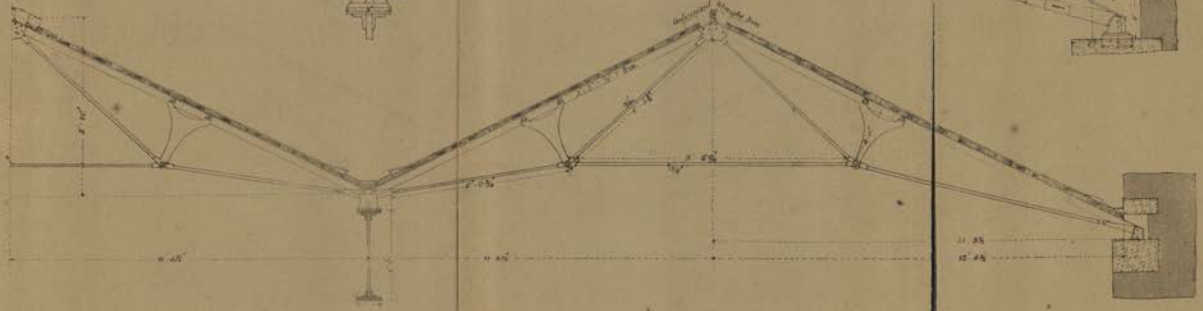
Drawn by Lockwood & Co. 7 Stationers Hall Court, Ludgate

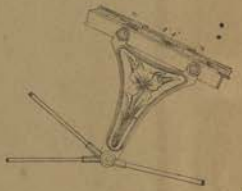
ABBEY MILLS PUMPING STATION.

BOILER HOUSE ROOF.



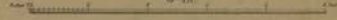






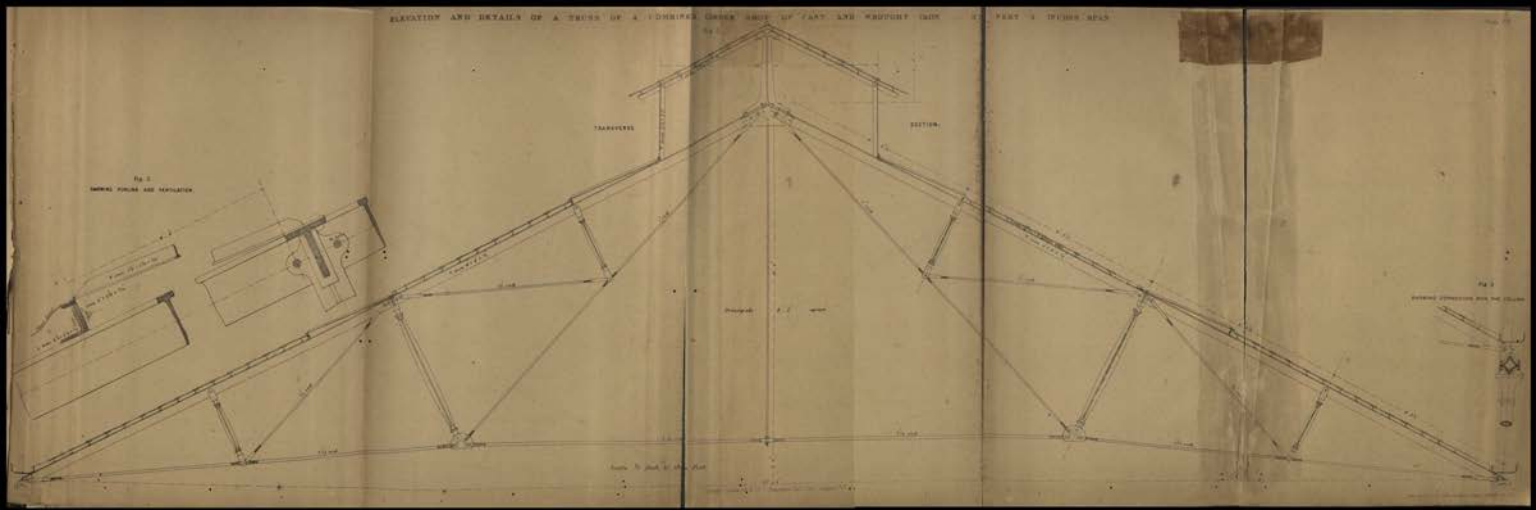
Scale for General Section.

Scale for Details.

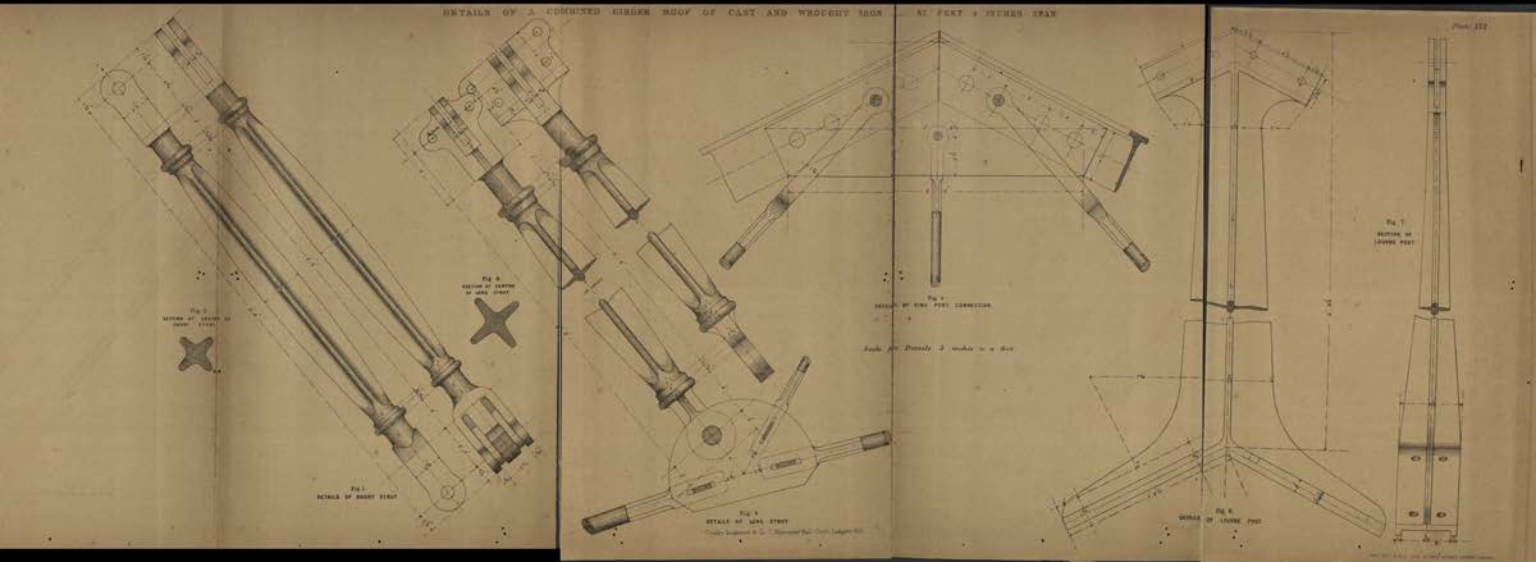


Crosby, Lockwood & Co. 7, Stationers' Hall Court, Ludgate Hill

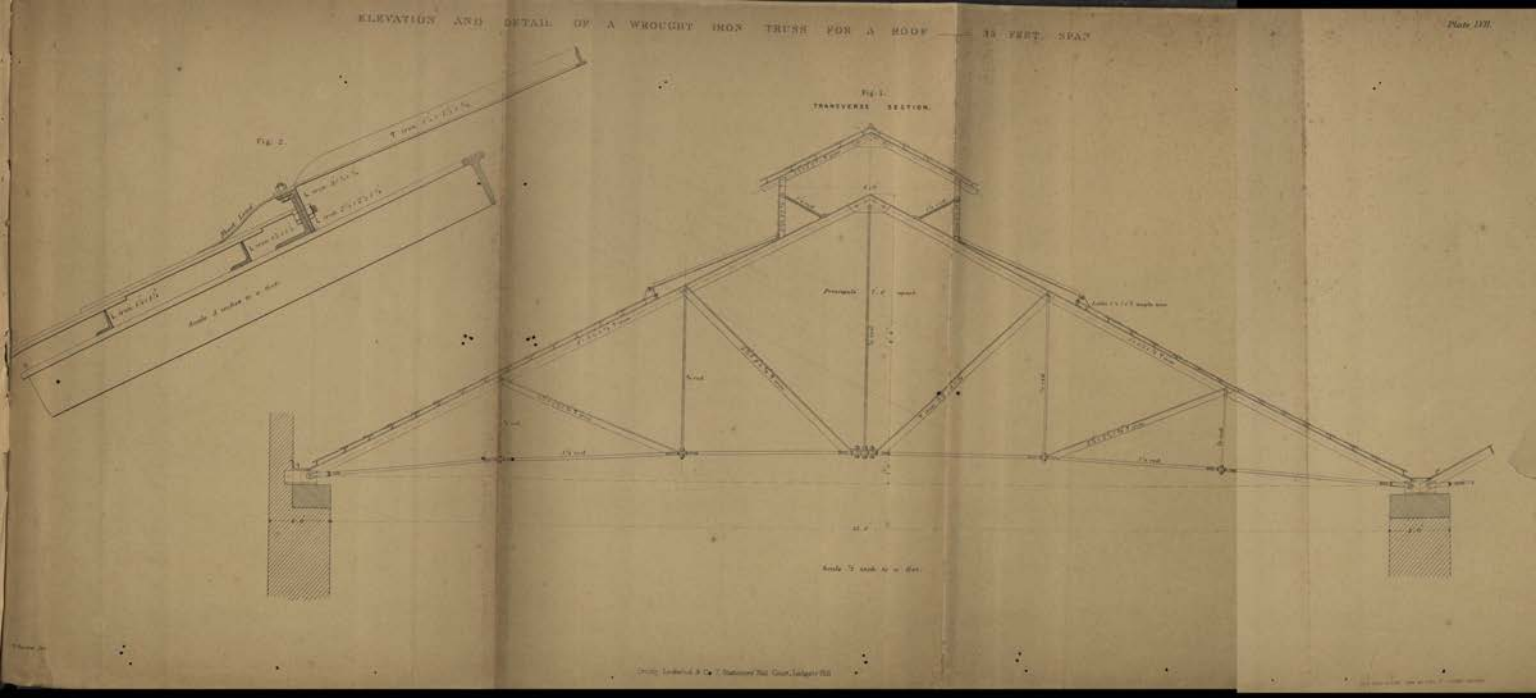
ELEVATION AND DETAILS OF A TRUSS OF A COMBINED [illegible] SHOP OF CAST AND WROUGHT IRON [illegible] FEET [illegible] INCHES SPAN



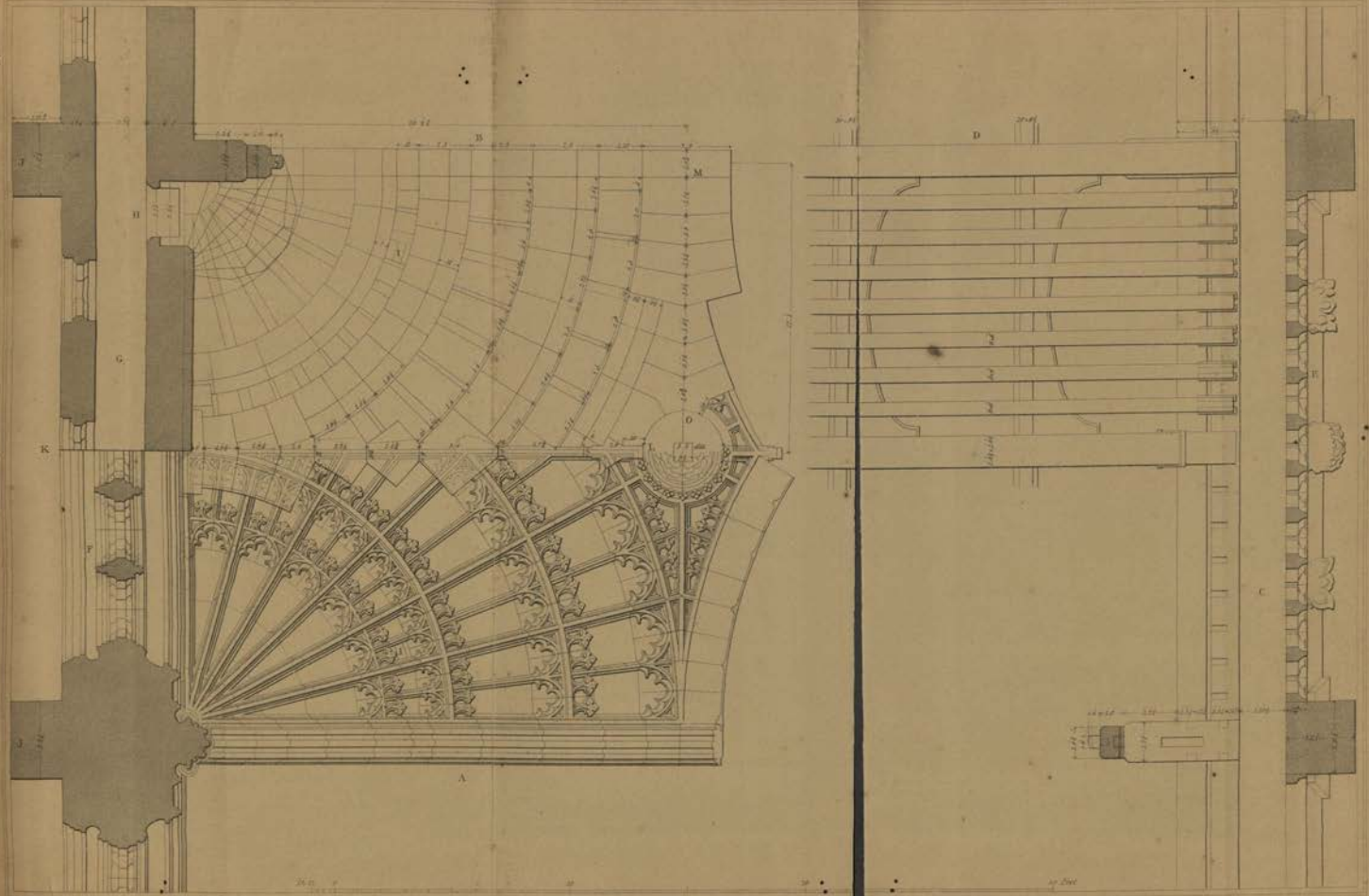
DETAILS OF A COMBINED GIRDER ROOF OF CAST AND WROUGHT IRON — 87 FEET 4 INCHES SPAN

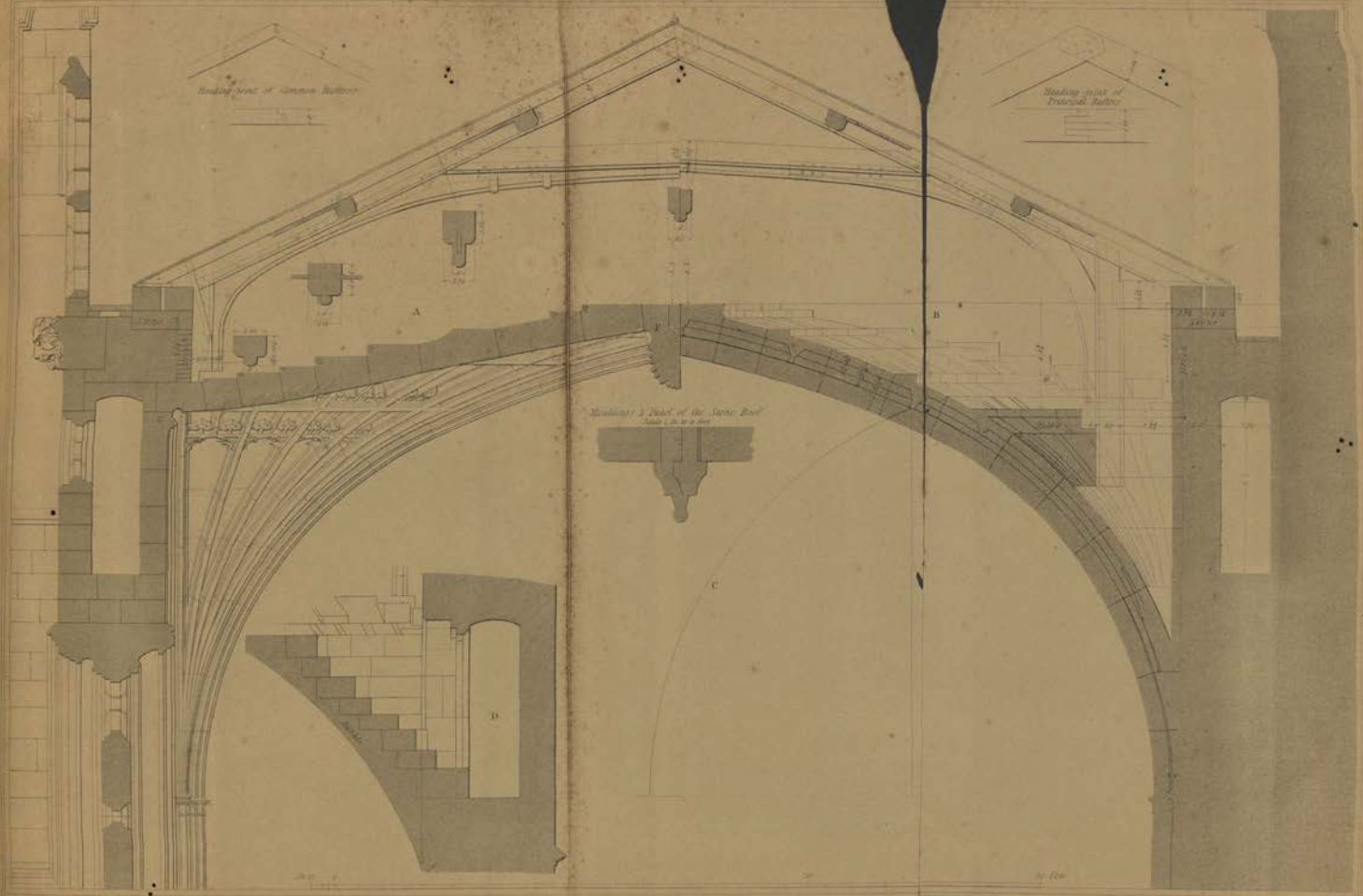


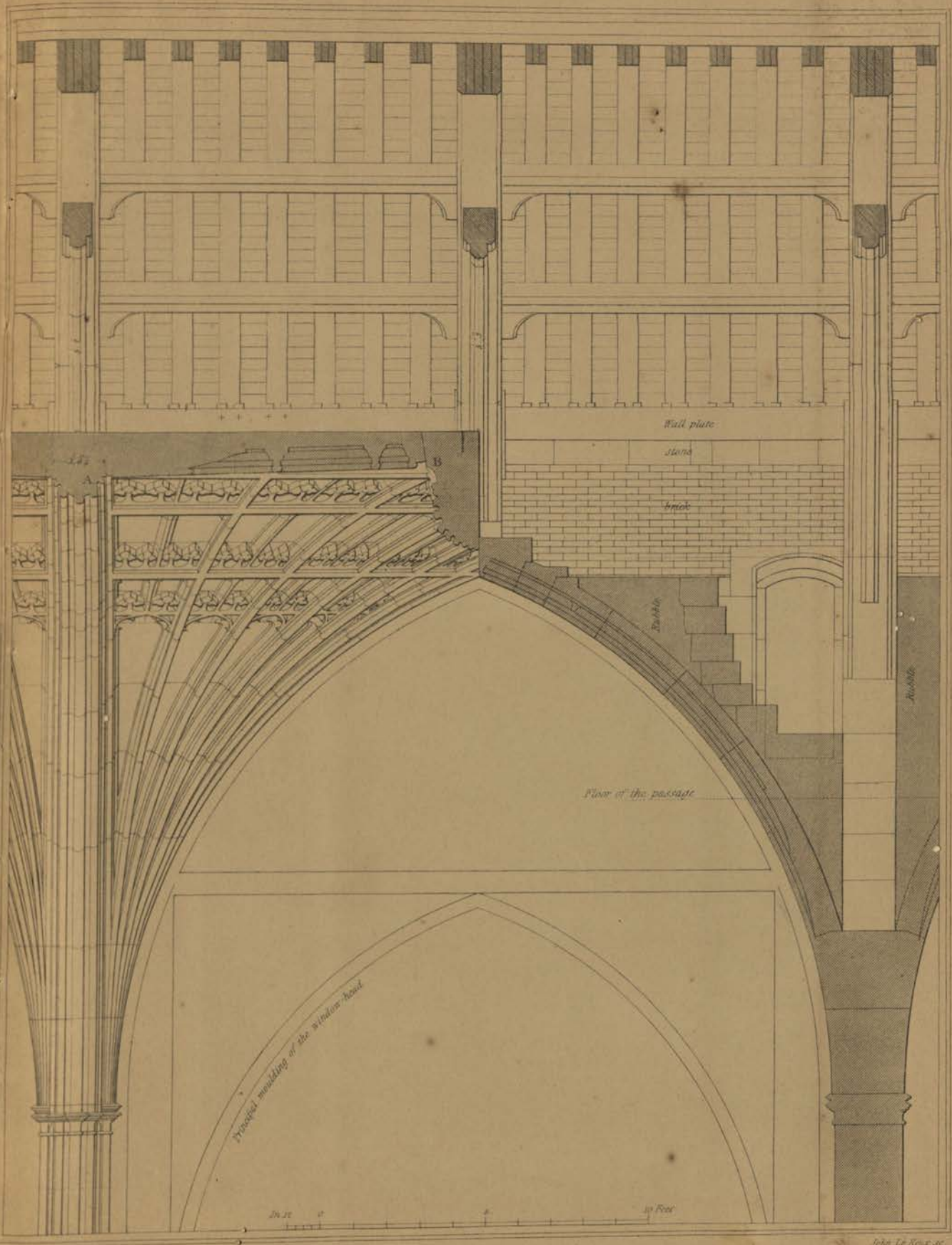
ELEVATION AND DETAIL OF A WROUGHT IRON TRUSS FOR A ROOF —— 35 FEET SPAN



Crosby, Lockwood & Co.'s Stationers' Hall Court, Ludgate Hill.


A
B
C
D
E
F
G
H
J
K
M
N
O


Heading joint of Common Rafters
Heading joint of Principal Rafters
A
B
C
D



F. Mackenzie del.

John Le Keux sc.

Crosby Lockwood & Co 7 Stationers Hall Court Ludgate Hill London EC

APPENDIX.

SPECIMENS OF VARIOUS ROOFS OF IRON AND STONE.

HAVING, in the preceding treatise, Art. 154, *et seq.*, investigated the several circumstances on which the stability, security, and durability of timber roofs depend, we have only, in this place, to give a brief description of the peculiarities relating to each of the roofs of iron and stone exhibited in the *Plates* XLIX. to LXI.

There is no part of the art of building which gives greater scope for the exercise of genius than that of the construction of a roof which shall be entirely appropriate to its specific object, in the situation and under the circumstances in which it is placed, whether it be for ornament, strength, or stability.

It is not many years since wood was the only material employed in the construction of a roof. Afterwards many of the principal parts were executed in cast-iron. Subsequently those parts acting as ties were made of malleable iron: and at present many roofs over manufactories, railway stations, &c., exhibit combinations of these materials well deserving of study, and of which several examples will be found referred to in the following description of the Plates. The revival of stone vaulting for roofs will also make the description of the beautiful roof of King's College Chapel, at Cambridge, interesting to the student of architecture.

DESCRIPTION OF THE PLATES.

Iron Roofs.

Plate XLIX. shows the roof over the Smithery at the Butterley Ironworks. This is a lofty building of its kind, in which the wrought-iron parts of steam-engines are fashioned ready for the lathe, the planing machine, or the file. It is 40 feet in width and 150 in length, containing two rows of smiths' fires. The roof is light, and consists of wrought- and cast-iron; those parts which act on the thrust being cast-iron, and those subject to tension being of wrought-iron: a better plan than using cast-iron alone. The principal frames are placed 15 feet apart, with two cast-iron side trees or purlins on each side, to which wooden rafters are spiked, holes being cast in the purlins for that purpose. Such a roof is less expensive than one composed of wrought-iron only, and it is also stiffer and not so liable to spring in heavy gales of wind.

The details are well given in the engraving, and we recommend this roof as useful for covering moderately large spans, as railway stations and the like, where it is not requisite to suspend any weight from the tie-bar.

Plate L.—Wrought-iron bowstring roof, by Richard Turner, civil engineer, of Dublin; made for the Clyde trustees for the quay at Glasgow: this roof is 700 feet long, and 70 feet span, and has cast-iron struts. The plate shows the transverse section and details of the principal parts to a larger scale.

Plate LI.—Wrought-iron elliptical arched roof with details, erected by Richard Turner, civil engineer, for Messrs. Joseph Whitworth, of Manchester, with dimensions. The span is 40 feet, and the rise at the centre is one-third of the span.

Plate LII.—Wrought-iron bowstring roof, with details, erected by Richard Turner, C.E., at the Galway terminus, Irish Great Western Railway, with dimensions. The span of this roof is 80 feet, and the design is similar to that on *Plate* L. The struts are of cast-iron, as well as the shoes for the feet of the rafters.

Plate LIII.—Elevation and details of curb roof to engine-house of the Abbey Mills pumping station, on the Thames below Woolwich, in connection with the southern outfall of the main drainage system. The struts are of cast-iron, with flanges at each end, the one to receive the rafters and the other the tie-bars, the connection being made by bolts of $1\frac{1}{4}$ and $1\frac{1}{2}$ inches diameter respectively. The hip principals are connected to the king-heads of the ordinary principals by a $\frac{5}{8}$-inch joint plate on the top flanges, rivetted with $\frac{5}{8}$-inch rivets. The principals are secured to cast-iron shoes, bolted through the cut stone into the brickwork of the walls by $1\frac{1}{4}$-inch bolts, cast-iron washer plates being used. The purlins are of deal, 7 inches × 3 inches, and are fitted one over ridge, one over shoes and struts, and two intermediates between large struts and ridges. The common rafters are of deal, 5 inches × 3 inches, notched over purlins, and secured to the ridge piece with wrought-iron knees and coach screws. One rafter occurs over each principal, and one intermediate. The bottom purlins are prevented from canting by wrought-iron straps, and the purlins are secured to the rafters by L-iron knees, bolted to the iron rafters, and fastened with $\frac{5}{8}$-inch coach screws. The span of this roof is 42 feet, and the height of the ridge above the top of the walls is 17 feet.

Plate LIV.—Elevation and details of one span of the roof over the boiler-house, Abbey Mills pumping station. The spans abutting on the walls are 25 feet 2 inches, and the inner spaces 22 feet 9 inches; all the parts are of similar section. The struts and shoes are of cast-iron, all the other members being of wrought-iron. These roofs, as well as that over the main building, are boarded and slated.

Plates LV. and LVI.—Elevation and details of a combined cast- and wrought-iron roof, of 67 feet 4 inches span, erected by Messrs. John Henderson, Porter, & Co., for Messrs. Vivian & Co., Copper Works, Swansea. The struts, shoes, sockets, and louvre post are of cast-iron, all the other parts being of wrought-iron.

Plate LVII.—Elevation and details of a small truss for a roof of 35 feet span entirely of wrought-iron, constructed by Messrs. John Henderson, Porter, & Co.

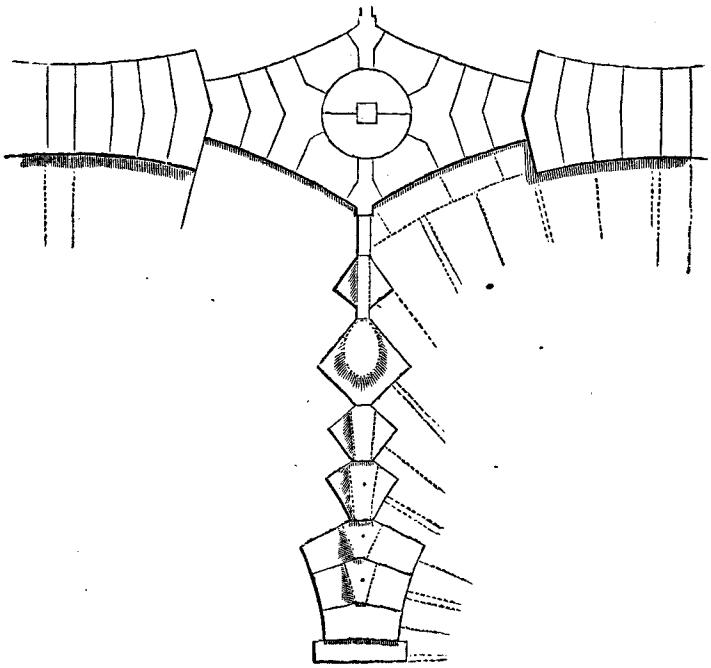
STONE VAULTING.

Roof of King's College Chapel, Cambridge.

Plates LVIII., LIX., LX., and LXI. are intended to illustrate the construction of the stone-vaulted roof of King's College Chapel, Cambridge, which was erected early in the fifteenth century.

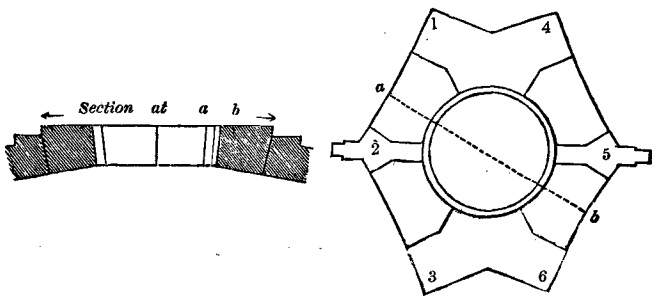
The whole roof of the chapel is divided by principal transverse ribs, springing from the opposite piers, into twelve oblong severies, each consisting of a vault formed of the four quadrants of an inverted concave parabolic conoid. Each quadrant is divided by vertical ribs, springing from a vaulting pillar on each side of the principal rib, into six compartments; of which the two between the diagonal rib and the principal rib are contained within smaller angles than the four others, the proportion of the oblong not admitting of their being equally divided. The principal rib receives the adjoining rib on each side in a rebate. Each compartment is subdivided by a smaller rib springing from the head of the lower tier of panels. The opposite diverging ribs meet at the junction of the four quadrants, where the longitudinal and transverse lines of intersection form ridges rising towards the centre of the vault, as the lines EF, *Plate* LIX. and AB, *Plate* LX. Each ridge consists of a continued series of keystones, one to each pair of ribs in the line KL, *Plate* LVIII., and two to each pair of ribs, joined over the centre of the rib, and the centre of the panel head, in the line OM, *Plate* LVIII. As the peculiar formation of these stones cannot be well expressed in the general plan and section, the subjoined woodcut (*Fig.* 39) is given in further illustration of this structure.

FIG. 39.



The back of the longitudinal ridge is on a level the whole length of the chapel. In the transverse ridge (*Plate* LIX., Section A), the stones are level within the dotted lines, and bevel off on each side. And where they meet the four upper stones of the diagonal ribs round the centre of the severy, the eight pieces together form a circle, as in the upper part of a dome. This circle contains the *central key*, which consists of two semicircular pieces and a square piece in the centre, where the Lewis, or whatever other machine was used for the purpose of lowering the key into its place, is supposed to have been inserted. The term *central key* is here used in preference to *principal key;* as it may be doubted whether it is so essential a point in the construction as the keystones of *the ribs*, which are indispensable. Considering the equilibrium produced in every part of the vault by the opposing forces, and how nearly the summering of the lines, 1 2, 2 3, 4 5, and 5 6 (*Fig.* 40) approaches to that of a dome, it might justify an opinion that it would stand securely if the circle were left open.

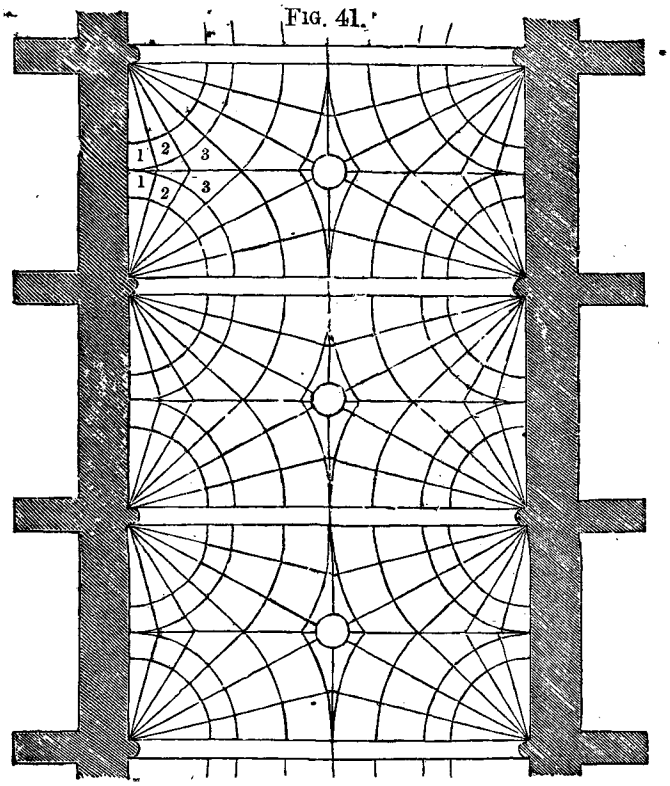
FIG. 40.



Mr. Ware (*Tracts on Vaults and Bridges*) says, speaking of Pendents, and after quoting this keystone of King's College Chapel amongst other examples, "These Pendents serve to illustrate the mechanical property in dome-vaulting, namely, that the eye may be of extraordinary gravity, or wholly omitted."

Each quadrant is also horizontally divided by three large and one smaller circular rib: the upper one meeting the longitudinal ridge at the vertex of the principal rib, and with the opposite ones forming a sort of "ridge lozenge." These horizontal ribs are concentric, and being only separated from those in the adjoining severies by the principal ribs, appear to form so many connecting lines through the whole roof, as shown in the following woodcut (*Fig.* 41). They are more substantial than the vertical ribs, being cut out of the same pieces of stone with the panel-heads, and rising in the form of a step above the back of the vaults.

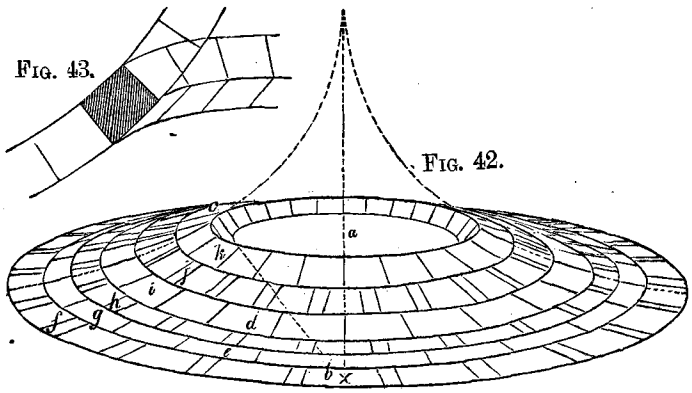
FIG. 41.



It has already been noticed that the vault is formed of the four quadrants (or rather of oblong portions of them) of an inverted concave conoid. In order to place this in the clearest point of view, *fig.* 42 is supposed to represent a figure of this form in perspective standing on its base, the base being prevented from spreading. The dark lines show the conoid partly constructed, and the dotted lines the whole figure in a complete state; the joints are like those of the vaulting of the chapel, but only half the number, to avoid a confusion of lines.

FIG. 43.

FIG. 42.



It will be seen that the vertical joints of the voussoirs at *c* (corresponding with one of the

horizontal circular ribs of the vault) diverge from a vertical line, *a b*, through the centre, and therefore the entire horizontal circle would stand securely on the principle of a dome, and the same with the circles *d e;* and the contrary summering of the vertical concave line, *f g h i j k*, &c. (corresponding with one of the vertical ribs), would resist a force from within the conoid in the direction *b c*. The opposite summerings are described in *fig.* 43.

If the conoid in a complete state were inverted and placed on its apex, the base being still prevented from spreading, it would stand on the same principle; each vertical line of stones being a portion of an arch strengthened by the resistance of the horizontal circular courses.

It has now been shown that, by the summering of the joints, the conoid would stand firmly, without any additional aid, either on its base or in an inverse position. Following up these observations as far as they are applicable to the subject, it will be seen that one-half of the conoid would stand against a sufficient abutment, *d* (*figs.* 44, 45); and if the wall (*b c*) on each side of the abutment be carried a little way over the semi-conoid, in order to give it additional firmness, it will be found to coincide with the construction of the *vault*, above which the face of the wall rests on the back of the wall-rib* overhanging the lower wall line about 5 inches (see *Plates* LVIII. and LIX.); and the curb at *d*, *fig.* 45, corresponds with the vaulting pillar.

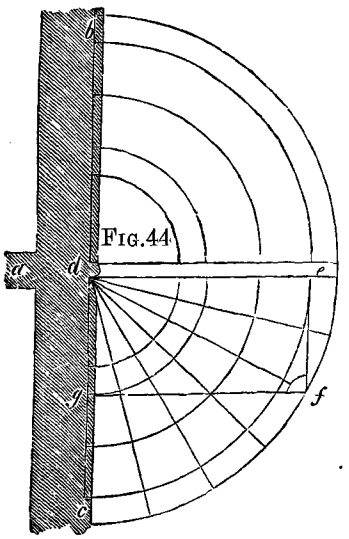


FIG. 44.

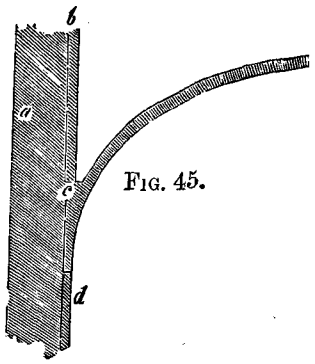


FIG. 45.

The portion of the conoid forming a quarter of one severy of the roof, is contained within the oblong *d e f g*, *fig.* 44; and four similar portions placed together, supported by the

* Malden says (account of King's College Chapel, 1769), on the authority of "a gentleman who has made the structure of many ancient Gothic buildings, and particularly that of King's College Chapel, his favourite study": "This roof is so constructed that it has no dependence on the walls between buttress and buttress on either side, or between tower and tower at either end of the chapel; the whole weight of the roof being so supported by the buttresses and towers, that if the above-mentioned walls should be entirely taken away, the buttresses and towers alone remaining, the roof would still continue as firm as it is at this hour." There can be

principal ribs *d e*, and supporting each other at their intersections *g f*, *f e*, will stand (being duly sustained on every side) on the same principle as the entire conoid, and together they form the general plan of one severy; but it will now be found that the ribs are of unequal length, and that in the inverted position of the figure the haunches have a much greater weight to sustain. It is true that the latter is counteracted by the spandrils being filled with rubble and mortar to the height of 16 feet above the springing-line, or a little above the haunch; but this was probably done rather for the sake of additional security than as an essential part of the work. The architect no doubt designed the construction upon the most perfect principle independently of any extraneous aid. It would then appear that the horizontal concentric ribs are not introduced for ornament only, as forming the panel-heads of the vault, but are also intended to equalise the bearing of the vertical ribs. The lower one is upon the weakest part of the haunch, and is calculated, by its circular form, to resist the lateral pressure from the vertex. The next is so near to it, that the two act in next in succession divides the bearing of the vertical ribs, and strengthens

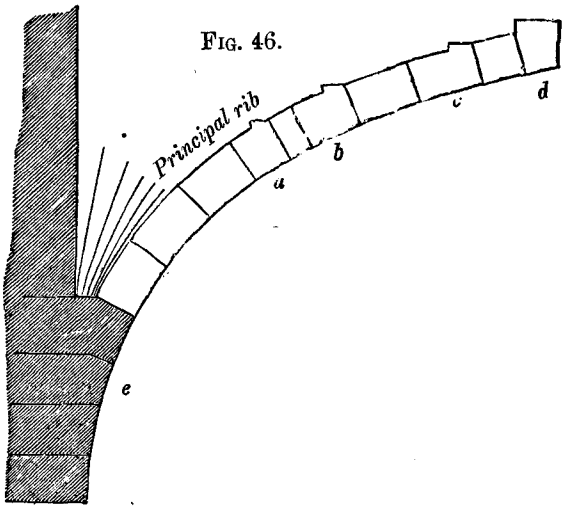


FIG. 46.

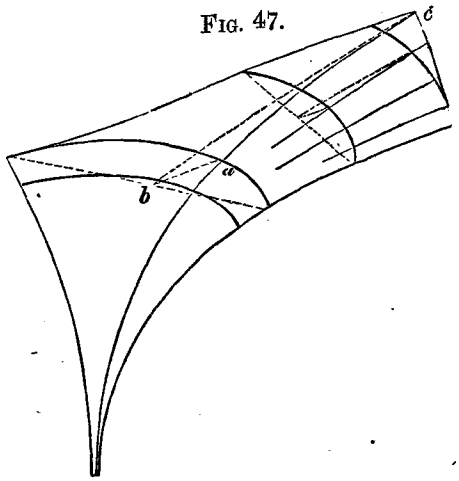
If one of the ribs, instead of being a component part of a vaulted roof, formed one side of an insulated arch (unless of such a form that the lines of pressure and resistance would pass through it from the vertex to the base) weights might be supposed to be placed on the points *a b c* (*fig.* 46), which in the vault are intersected by the horizontal ribs; and in order to produce an equilibrium, the greatest weight would be required on the lowest point, and diminishing

very little doubt that it would stand, but the point in the construction noticed in the text (which is very commonly met with in Gothic buildings of all ages) makes it very doubtful whether, in the opinion of the architect, it would be equally secure.

"The real author of this work (Malden's) was Dr. James, one of the Fellows and Master of Rugby School" (Upcott's *Bibliographical Account of Works relating to Topography*). It appears, by an appeal to the public in the Preface, that it was done as a means of relieving Malden, who was Chapel Clerk of King's College, and in distressed circumstances.

over each successive point to the vertex, where a greater weight, or a position of the materials equivalent to it, would be required. But in a vaulted roof of this form, where a horizontal resistance can be obtained, no additional weight is necessary, because the plane of the horizontal rib and the line of pressure form an angle *a*, *below* a line *b c* (*fig.* 47) drawn from the chord of the quadrant to the vertex; therefore the thrust cannot possibly throw the haunch *up;* and as the horizontal resistance at each successive point (rising towards the

FIG. 47.



vertex) consists of a segment of a larger circle, it would be proportionably weaker, if it consisted of stones of the same substance as the smaller circle; they are therefore found to increase in size from the haunch upwards, as *a b c* (*fig.* 46). The upper one (*d*) is within the longitudinal line of keystones. The horizontal ribs serve also as a counterpoise to the ridges and to each other, and by these several operations produce a general equilibrium. The thrust of the circular ribs, in the direction of the transverse ridge towards the wall over the windows, is discharged to the buttresses by the opposing ribs 1 1, 2 2, 3 3, &c., *fig.* 41.

The lower part of the vertical ribs *e* (*fig.* 46) is solid to the height of several feet above the spring—how high cannot be ascertained, the spandrils being filled up; but probably nearly as high as the level of the passage along the wall, though it is not represented so high in the *Plate* LIX. Therefore the lines of pressure and resistance will not be from the spring, but from the part where the ribs unite, that being the real abutment of the vault; but even from this level the ribs are not of sufficient substance for the lines to pass through them in one length to the vertex; and consequently they require the assistance of the horizontal ribs.

This part of the structure shows the wide difference, and in some points even opposite effect, between the actual and apparent, or rather "mechanical and decorative construction," as they are aptly termed by the author of *Remarks on the Architecture of the Middle Ages*, in his excellent observations on this subject.

In the mechanical construction the springing of the vault, from the top of the vaulting

pillar to the point at which the ribs become divided, is, in fact, though unseen, a very substantial corbel, built into the wall and forming a firm abutment to the superstructure; which portion of the work, in ruins of Gothic buildings, may be observed to remain with the wall rib, or the stones of the groin immediately attached to the wall, after every other part of the vault has fallen in.

In the decorative construction each quadrant of the vault rises from an extremely slender vaulting pillar; the ribs, formed of the lightest mouldings, appear to be tied together by bands of the same light character, dividing the vault into tiers of cinquefoil-headed panels, crowned with a delicate leaf ornament, which entirely conceal the substantial mechanical construction on an opposite principle, as displayed on the extrados; the ridges appear to be of the same slender form as the ribs, and the whole structure to be held together by the central keystone.

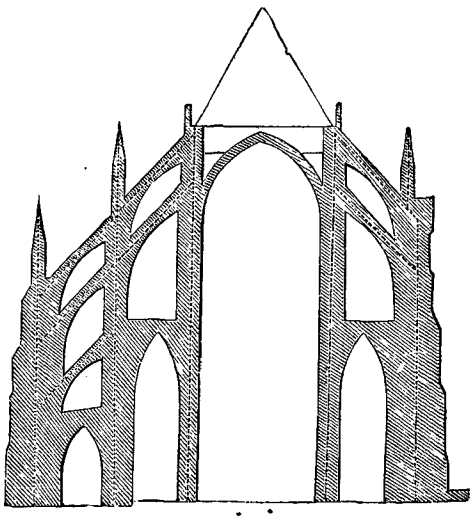
These appearances, for the most part so different from the fact, though exactly agreeing with all the leading lines of the mechanical construction, are well calculated, in a vault of this magnitude, to create feelings of astonishment in the minds of general observers wholly unacquainted with its mechanism.

The panels are laid in rebates at the back of the ribs, and are found to vary from 2 to 6 inches in thickness. Above the rubble the inner face of the wall is of brick, but the passage behind it is of stone. Except the brickwork here mentioned, the whole of the roof and pinnacles are of Weldon stone; the ribs and panels being of the same material.

The great pinnacles over the buttresses in this and most other Gothic churches are opposed to the hypothesis, that the architects of the Middle ages adopted the catenarian principle. Had they done so, they would have taken care to carry their work through without disturbing the properties of the catenary supposed to be contained within the thickness of the walls and vault; but, on the contrary, they placed a ponderous timber roof, frequently without sufficient tie, immediately over it, requiring lofty and massive pinnacles to resist its thrust. Thus, if they began upon the principle of the catenary, they were obliged to apply a very different principle before they finished their work, to prevent the failure of the first, which is totally at variance with the great skill displayed in the execution of their bold designs. As the catenary may be more or less elongated, a catenarian arch may be described through the section of almost any building; but in every instance a *straight line* may also be drawn in the *same direction* from the base of the buttress to the vault, in an angle calculated to resist the lateral thrust: this might as reasonably be supposed the line of resistance as the catenarian curve, and would coincide with the principle observable in the flying buttresses, which consist of a *straight line* supported on a curve which is usually a segment of a circle; and whenever a double range of flying buttresses is met with, as over the south aisle and cloisters of Westminster Abbey, the second is almost always continued in the same direct line with the first. Even in the compound form of that of Henry VII.'s Chapel, the straight line is not omitted. Had the catenaria been their great principle of construction it would be apparent in the aisles, the arches, and every other important part of the edifice, and not merely confined to the buttresses and principal vaulting: but it would be difficult to describe a catenarian arch passing through some of their lofty arches supported on slender columns, without carrying the foot of the catenary outside of the base; in the Lady Chapel of Salisbury Cathedral, for

instance: and it would be wholly impossible to apply it to many Tudor arches: for if any portion of the line passes above or below the thickness of the vault, it is evident that a link of the catenary is broken in that part, and therefore it can no longer be supposed to exist; which, if it ever did, the thickened spandrils, pinnacles, and other weights that are always put upon the supposed arch, would completely destroy the equilibrium. It is more probable that these weights were expressly used for the purpose of giving stability to the structure;* and the old architects calculated, and, experience shows, calculated correctly, on the balance being established between the lateral and vertical thrusts and resistances, of which their whole structure consists, as illustrated in the following woodcut (*fig.* 48) of Westminster Abbey. The dotted lines through the buttresses and pinnacles represent some of the principal lines of resistance.

FIG. 48.



The timber roof has been thought by some to be built entirely of chestnut, but it seems probable that it is of a species of oak (see Art. 404), and is framed with a truss over each pier, and one over each window. The truss over the pier rests on a stone projection in the spandril of the vault, built out from the wall, which would otherwise be weak at this point, being against the passage. Against this projection is placed a post, supporting the principal rafter above, and cut with a projecting curb towards the lower part, to receive a curved bracket, the back of which, at the lower end, is tongued into the post, and at the upper end into the principal rafter, and fastened with wooden pins, as are all the joints throughout. Between this bracket and the collar-beam (which is cut in a bent form) is another piece, also curved. This

* Existing documents relating to the construction of the chapel, afford strong collateral evidence of this, viz.:—The contract for erecting the *pinnacles* is dated *Jan.* 4, 1513, and the mason is bound to finish them *before the Feast of the Annunciation next ensuing.* The contract for erecting the *vault* is dated *Feb.* 8, 1513, to be finished in three years. Here it is seen that the pinnacles were first considered, and that ample time was allowed for all of them to be completed, at least before the centering of any of the severies of the roof was struck.

piece is secured to the principal rafter and to the collar-beam (which is cut with an abutment to receive it) by a key inserted into the three (as expressed by the dotted lines in the section, *Plate* LIX.); and this piece, the bracket, and the collar-beam, together form an arch. An inter-tie, resting on the wall, is fixed to the back of the post, and receives the foot of the principal rafter. Between the trusses, and tongued into the inter-ties, are double wall-plates; the inner one supports the foot of the principal rafter of the truss over the window, and the outer one receives the common rafters. Between the principal rafters, and tongued into them, and rabbeted on to the back of the purlins, are boards cut in the form of arches.

The truss over the window has no inter-tie, and the post stands against the wall, instead of against a projecting pier. In all other respects it is framed in the same manner as the other truss; but the collar-beam is rather lower. (See *Plate* LIX.)

Under the foot of the common rafters, on each side of the tenon, and stretching partly over the inner wall-plate, is a small piece of wood (†††† *Plates* LVIII., LIX., LX.) raising the foot of the rafter about $1\frac{1}{2}$ inches above the wall-plate, the intention of which could not be ascertained, as its enclosed situation precluded the possibility of examining it. There has recently been a block fixed on to the inner wall-plate behind the foot of each common rafter, which is omitted in the engravings. In the Section (*Plate* LIX.) some iron straps are shown; but they are only partial, and should also have been omitted, being no part of the original work, in which no iron or nails were used. The timbers are very heavy, as may be seen by the dimensions figured in the plates; but by means of the posts and brackets the pressure is thrown as low down the wall as the stone roof will allow.

DESCRIPTION OF THE PLATES.

Plate LVIII.—A plan of the fan tracery of one quadrant. B. The extrados. C. The wall above the vaulting, showing the wall-plates, &c. D. A portion of the timber roof complete. E. Plan of the parapet. F. Half plan of one of the windows. G. Passage in the wall over the windows. H. Doorway and steps communicating with the upper part of the stone roof. (There is a corresponding communication with the passage on the south side, and the same is repeated at each severy.) II. The corresponding panel in each severy is joined in a similar manner to these, supposed to have been left open for the purpose of communication during the progress of the work. JJ. Upper part of the buttresses.

Plate LIX.—A. Section through the transverse ridge, and truss over the window, at the line K, L, *Plate* LVIII. B. Section through the principal rib, and truss over the pier, at M, N, *Plate* LVIII. C. Form of the wall-rib over the side windows. D. Section of the passage, with one of the doorways and steps leading to the upper part of the stone roof.

Plate LX.—Longitudinal Section: one-half through the ridge, and the other half close to the wall, showing the front of the projecting pier in the spandril of the vaulting which supports one of the trusses of the timber roof; and the doorway leading to the passage. The

situation of the window-head is here indicated for the purpose of showing, with the plan and section (*Plates* LVIII., LIX.), the form of the wall and parapet, and their connection with the buttresses.

Plate LXI.—General section through the buttresses, showing also the vestries or chantries built between the buttresses, the walls, and the parapet. The only communication between the chantries on each side of the choir is by a small doorway through each buttress; and similar openings above form a passage along the roof of the aisles.

INDEX.

The Numbers refer to the Pages.

A.

PAGE

ABBEY Mills pumping station, roofs of... ... 302
Abele, see Poplar.
Abutments, curved, for joints 214
——— for bridges 191
Abutting joints 214
Acacia described 276
—— experiments on the stiffness of 72
—— experiments on the strength of 74
African oak 281
Age of trees 226
Air, circulation of, when of use in stopping the dry rot 247
Alburnum 226
Alder described 269
—— felled in summer durable 228
—— experiments on the stiffness of 72
—— experiments on the strength of 73, 77
Alkalies, effect of, on timber 249
American timber, strength of 75
Angle of repose 157
Annual rings in timber 224
Ants, white, destroy timber 254
Arches, often improperly applied 245
——— construction of timber 195
——— span of timber, limit of 189
——— thrust of, computed 192
Arch-stones, pressure of, on centres 159
Arsenic used to preserve timber from white ant 255
Ascent of bridges and roads 189
Ash described 273
—— experiments on the stiffness of 72
—— experiments on the strength of ... 67, 68, 73
Aspen, see Poplar.

B.

PAGE

Bamberg, bridge of... 182
Bark of trees 225
Barking trees 228
Barlow's experiments on strength of timber ... 73
——— experiments on detrusion 54
Barn floor, description of dry rot in 244
Basalt, specific gravity of 298
Basilica of St. Paul at Rome, roof of 109
Beams, equilibrium of an assemblage of 28
——— pressure of inclined 19
——— stress upon horizontal 22
——— resistance of, to tension 37
——— of the stiffness of, supported at both ends 41
——— strongest form of 42
——— stiffest from a round tree 41
——— experiments on the stiffness of 69
——— practical rules for the stiffness of ... 43
——— on the strength of 50
——— experiments on the strength of 73
——— strongest from a round tree 52
——— resistance to compression 55
——— tie, rules for dimensions of 129
Beech described 268
—— experiments on the stiffness of 72
—— experiments on the strength of 73
—— felled in summer least subject to worms ... 228
Bent timber 55
Bevan's experiments on resilience of timber ... 66
Bevels for purlins in hipped roofs... 135
Binding-joists, rules for the strength of 92
———— joints for 211
———— table of scantlings for 98
———— to carry ceilings, table for... ... 100

	PAGE
Birch, experiments on the stiffness of	72
—— experiments on the strength of	67
Birmingham Theatre roof	108
Blackfriars bridge centering	163
Blocks under tie-beams	130
Boiling timber, remarks on	232
———— in alkaline solutions, remarks on ...	249
Bolting on straps	221
Bolts, sometimes used instead of straps	221
Bond timber often improperly used	245
Brass, specific gravity of	298
Braces, rules for strength of, for roofs	133
——— joints proper for	215
——— for partitions, how most effectually applied	154
Brenta, bridge over the	174
Bressummers	91
Brick, specific gravity of	298
Brickwork, weight of a cubic foot of	298
—— damp, a cause of dry rot	245
Bridges, curve of equilibrium for	189
——— foot	198
——— laminated timber	198
——— on centres for	156
——— on wooden	174
——— of Sublicius...	174
——— of Cæsar	174
——— of Trajan	174
——— of the middle ages	174
——— of Palladio	174
——— across Portsmouth and other rivers in North America	175
——— of Schaffhausen	180
——— of Freysingen	180
——— of Bamberg...	182
——— of Ettringen	182
——— of Mr. Burn, notice of	183
——— table of the principal dimensions of Wiebeking's...	183
——— table of principal wooden, in Europe ...	184
——— on the design of	184
——— on the width of	185
——— on the waterway for	185
——— on the span of	188
——— on the ascent of	189
——— on the rise of	201
——— on the abutments of	191
——— on the piers of	193
——— on the construction of the arches for frames of	195
——— on the settlement of	201
——— on the roadway and parapets of	201
Bridges, on the scantlings of timber for	202
Bridging-joists, on	93
———— table of scantlings for	99
Brunel's timber viaducts	205
Building beams	90
—— strictures on a bad method of	245
—— on timber, dangerous consequences of ...	248
Butterley, roof at	301

C.

	PAGE
Cæsar's bridge across the Rhine	174
Cajeput oil on timber	255
Cambering tie-beams, remarks on...	130
Cambridge, stone vaulting of King's College Chapel	303
Carpenter's boast	215
Carpentry defined	1
Carvings, durability of	256
Cast-iron, cohesive force of	69
——— shoes	216
——— sockets	219
——— tie-beam plate	219
Cedar of Libanus described	284
—— experiments on the stiffness of	72
—— experiments on the strength of	67
—— red, described	294
Ceiling-joists, rules for	94
———— table of scantlings for	100
Ceilings, precautions required to form good ...	83
Cement, specific gravity of	298
——— secures walls from damp	247
Centre of gravity, how to find the	16
——— of pressure	25
Centres for bridges	156
——— pressure of the arch stones on	159
——— on designing	160
——— of Chester Bridge	165
——— of Conon Bridge	160
——— of Coldstream Bridge	160
——— of Neuilly Bridge	161
——— of Waterloo Bridge	161
——— designs for	157
——— on construction of	162
——— on removing	163
——— on computing the strength of	165
Chalk, specific gravity of	298
Changes of form in framing dangerous	5
Characters of woods	259
Charcoal, quantity of, in different woods... ...	258

PAGE

Charring wood, on 233
Cherry tree, experiments on the stiffness of ... 72
Chesnut described 271
——— experiments on 273
——— experiments on the stiffness of 67
——— experiments on the strength of 73
Christiania deal 288
Christ's Hospital, roof of the hall of 111
Chloride of mercury for preserving wood ... 251
——— of zinc for ditto 252
Church, roof... 122
Classification of woods, on the 259
——— table of 260
Clay, specific weight of 298
Coal tar, effect of, in dry rot, &c.... 254
Cocking a tie-beam on the wall-plate 130
Coffer-dams 172
Cohesive force of woods 67
——— of iron 69
——— defined 260
Coldstream Bridge, centre of 160
Collar-beam, joint for 215
——— roofs 105
Columns, on the resistance of 58
——— bent 59
——— strongest form of 59
——— practical rules for strength of 61
Compass timber 55
Composition of forces, on the 3
Compression, on the resistance to... 55
——— experiments on 77
——— at the joints of framing 57
Conon Bridge, centre of 160
Construction of floors 83
——— of roofs 101
——— of domes and spires 142
——— of partitions and frame houses ... 152
——— of centres and scaffoldings ... 156
——— of bridges and viaducts 174
——— of scarfs and joints 207
——— of timber arches for bridges ... 195
Copper, weight of covering of 102
——— used to prevent damp 247
Copperas, effect of, in preventing decay 248
Corrosive sublimate, a remedy against rot ... 249
Couch's experiments on seasoning 236
Cowrie, or Cowdie pine 294
Cranes, on the construction of 11
Creosote used to preserve timber 254
Cross strains, resistance to 38

PAGE

Crushing, on the resistance to 55
——— experiments on 77
Cubic parabola, method of describing 31
Cupola, curve of equilibrium for 32
——— on the construction of 142
Curb roofs, remarks on 106
—— failure of timber, St. Mark's, Venice ... 246
Curved ribs, roof with 115
——— tables of scantlings for 139
——— strength of 164
——— radius of curvature of 199
——— depth of beams for 200
Curve of equilibrium, on the 30
——— for domes 32
Cylinders, rules for stiffness of 46
——— for strength of 52
——— hollow, strength of 52

D.

Damp walls, to prevent 247
——— a cause of decay 245
Davy on difference between oak and chesnut ... 272
Deal, red (see Fir).
—— white (see Fir).
Decay of timber, on the 241
——— from continued dryness 241
——— from continued wetness 241
——— from alternate dryness and moisture ... 241
——— from moisture with heat 242
——— internal 243
——— progress of 244
——— prevented by wetness 244
——— stoves sometimes a cause of 245
——— on the prevention of 247
Decomposition of timber 242
Deflexion, quantity allowed for, in the rules ... 43
Delorme's system of roofs 118
Designing framing, &c., on 34
Design of centres for stone arches. 160
Detrusion, on 54
——— experiments on 68
Diagrams of stress 7
Direction of pressures, how determined 21
Dicotyledons 225
Dock roof, remarks on 122
Dome, curve of equilibrium for 32
——— on the construction of 142
——— thrust of 144
——— scantlings for 143

PAGE

Dome, failure of a 246
——— of the Invalides, Paris 143
——— of St. Paul's, London 143
Dovetail joints, on 216
Drains, precautions respecting 247
Drury Lane Theatre, roof of 108
Dry, in seasoning, defined 239
Dry rot, on 243
—— on repairing buildings affected with ... 251
Drying buildings, on the good effects of 247
Dubuat's experiments on rivers 186
Duhamel's experiments on the stiffness of oak beams 42
Durability of wood in salt mines 248
———— in piles 255
———— buried in the ground 255
——— of framed timbers 256
——— of old timber, causes of 257
——— of woods exposed to the weather, experiments on 258
——— of different kinds of wood... 257
Dutch method of preserving timber 252

E.

Earth, a cause of damp 247
—— specific gravity of 298
Elasticity of timber, on the 261
———— on the modulus of 37
Ellipse, to describe on a large scale 20
Elm, kinds of, described 275
—— experiments on the stiffness of 72
—— experiments on the strength of 67
Epidermis of trees 225
Equilibrium of an assemblage of beams 28
—— curve of 30
———— for domes.. 32
Ettringen Bridge 182
Evelyn on felling timber 227
Exogens 225
Experiments on the cohesive force of woods ... 67
—— on the lateral cohesion 68
—— on the stiffness of beams 69
—— on the strength of beams 73
—— on the compression of beams 78
—— remarks on making 60
—— on the resistance to crushing 77
—— on resistance to compression at joints ... 57
—— on the strength of floors 83
———————— pillars 62

PAGE

F.

Fall of water under a bridge, to determine ... 187
Felling timber, on 227
Felling, when trees are of a proper age for ... 227
——— on the proper season of the year for ... 228
Fender piles to piers of bridges 194
Fir, red or yellow, described 285
Fir, white or spruce, described 287
—— experiments on the stiffness of 71
—— experiments on the strength of 67
—— experiments on the resistance of, to compression 77
Fishing a beam 208
Flexure, the resistance to, of most importance ... 37
Flitch girders 87
Floating timber in docks and rivers a cause of decay 244
Flooring, naked, described... 83
———————— single-joisted, on 84
———————— double, on 83
———————— framed, on 85
———————— framed, on experiments on the strength of 83
Floors, general remarks on 94
——— Serlio, of short timbers 95
——— curious one at Amsterdam 95
——— means of securing from dry rot 246
Florence Cathedral, roof of 111
———— Academy of Fine Arts, roof of... ... 111
Fluids, pressure of 24
Forces, experiments to show the action of ... 4
——— their effects, how to measure 6
——— composition and resolution of 3
——— parallelogram of 4
——— polygon of 15
Footbridge over the Farnham and Alton Railway 175
Fracture, on the points of, in a system of framing 28
Frame-houses 155
Framed partitions 152
Framing floors, on 85
Framing, to measure the strains in 6
———— to distinguish ties from struts in ... 12
———— points of fracture in a system of ... 28
———— curve of equilibrium in a system of ... 30
———— on designing 34
———— on the strength of joints for 57
———— for spanning a wide opening 191
———— on the joints of 212
Freysingen Bridge described 180

PAGE

Friction of stones, on 157
Fungus, a product of decayed timber 244
——— not destroyed by a slow current of air ... 248

G.

Galvanising iron 221
Gantries 167
Gates, level crossing 206
——— painting of, sometimes a cause of decay... 246
Genoa, roof over the Exchange at... 121
Geometry essential to carpentry 1
Girard's experiments on the resistance of beams to compression 79
Girders, on, with rules for dimensions of... ... 85
——— on reversing and bolting 87
——— flitch 91
——— trussed, remarks on 88
——— Mr. Barlow's experiments on ... 88
——— on forming, for long bearings 90
——— remarks on laying 91
——— table of scantlings for 97
Girdling trees 228
Gothic builders particular in the choice of timber 262
——— roofs, on 123
Granites, specific gravity of 298
Gravity, centre of, how to find 16
——— specific, table of, for woods 296
——— table of, for various materials ... 298
——— remarks on determining 300
Great Northern Railway roof 117
Green copperas a preventive of decay 248
Ground joists, on scantlings of 93
——— floors, to secure from decay 248
Growth of trees 225
Guide-piles 172

H.

Halving timbers 105
Hammer-beam roofs 123
Hardness of woods, &c., on the 261
Heart-wood, formation and nature of 225
Heat a cause of dry rot when moisture is present 242
Herbaceous envelope of trees 225
Herring-bone strutting 85
Hipped-roofs... 135
Hodgkinson experiments on pillars 57
——— on crushing strength... 77
Honduras mahogany described 278

PAGE

Honduras mahogany, experiments on 72
Horizontal thrust of a roof, &c., how to measure 20
Horse chesnut, experiments on the stiffness of ... 72
Houses, strictures on the London method of building 245
Houses of Parliament, cofferdam for 172
——— scaffolding for 168

I.

Ice-breakers 194
Inclined beams, pressure of 20
——— stiffness of 44
Indian oak (see Teak).
Insects, to preserve timber from 252
Internal decay, example of... 243
Iron roof at Butterley 301
——— at Glasgow 302
——— at Manchester 302
——— at Galway 302
——— at Abbey Mills 302
——— at Swansea 302
—— cohesive force of 69
—— to preserve from rust... 223
—— bolts, on 221
—— straps, on 220
—— shoes, on 216
—— sockets... 219
—— sulphate of, effect of, in preventing dry rot 248
—— specific gravity of 298

J.

Jack rafters, bevels of 136
Jib of a crane, strain on 11
Joints, pressure upon, how to estimate 15
—— strength of 57
—— method of securing against decay 181
—— on the construction of 211
—— to resist tension, on 208
—— to resist cross strains, on 210
—— to resist compression, on 211
—— of framing, on... 212
—— for ties and braces, on 215
—— on dovetail 216
Joists, common rules for 84
—— binding, rules for 92
—— bridging, on 93
—— ground, on 93
—— ceiling, on, with rules 94
—— common, table of scantlings for 99

PAGE

Joists, binding, for floors, table of scantlings for 98
———— for ceilings, table of scantlings for 100
—— bridging, table of scantlings for 99
—— ceiling, table of scantlings for 100

K.

Keys for scarfs 208
King-posts, on, with rules for 127
———— straps for 220
King's College Chapel, Cambridge, roof of ... 303
Kirkaldy's experiments on pillars 81
Knots, the strained side of a beam should be free from 23
Kyan's process for preventing decay 249

L.

Lamandé's experiments on the resistance of beams to compression 78
Langton's method of seasoning 234
Lantern of a dome 145
Larch described 290
—— experiments on the stiffness of 71
———— on the strength of 68
———— on resistance to crushing ... 292
—— American black 291
———— red 291
Laslett's experiments on timber 68
Lattice bridges 176
Layers, annual, of trees 224
Lead covering, weight of 102
—— sometimes put in joints 215
—— used to prevent damp rising in walls ... 247
Lean-to roof 104
Lebanon, cedar of 284
Lengthening timbers 208
Level crossing gate 206
Levers, on framed 10
——— strains in framed, the same as in a solid beam 10
Life of trees 226
Lime, quick, a cause of decay 242
———— preserves timber from worms ... 252
—— tree, experiments on the stiffness of ... 72
Loam used formerly for bedding girders, &c. ... 245
Lock gates 26
London Bridge, fall of water under 187
———— durability of the piles of ... 255
———— centering for 162

PAGE

London Bridge cofferdam 173
Loss of weight by seasoning 235

M.

M-roof 104
Mahogany, kinds of, described 277
———— experiments on the stiffness of 72
———— experiments on the strength of 68
Mansard roof 106
Maple, experiments on the stiffness of 72
Mar Forest timber 287
Maxwell's method of diagrams 7
Mechanics, a knowledge of, essential in carpentry 1
Medullary rays 226
Middle ages, bridges of 174
Modena, palace at, roof over the riding-house of 121
Modulus of elasticity, on the 261
Moisture the chief cause of decay 245
Mortar a cause of rottenness 242
——— specific gravity of 299
Mortising 211
Moscow, roof of riding-house at 117

N.

Nails, resistance to drawing 222
—— how secured from rust by slaters 223
Naked flooring, on 83
———— rules for dimensions of timbers of 84
———— general observations on 94
———— short timbers 95
Needling 170
Nelson's Column, scaffolding for 167
Neuilly Bridge, centre of 161
Neutral axis of a beam 38
Norway spruce 288
——— timber 285

O.

Oak, kinds of, described 263
—— experiments on the stiffness of 69
———— on the strength of 68
———— on the strength of pillars ... 80
———— on the resistance of, to compression 78
—— Turkey 266
—— Riga 266
—— Dantzic 266

PAGE

Oak, Italian 266
—— French 266
—— Evergreen 266
—— experiments on the English species 264
—— Durmast 265
—— American species of 265
—— properties of different kinds of 267
Oblique pressures, how measured 19
Odoriferous woods most durable 257
Oil useful as a preventive of worms 255

P.

Paint, effect of, on unseasoned wood 246
—— rendered more durable by sanding 252
Painted floor cloth a cause of decay 246
Palazzo Vecchio at Florence, roof over 110
Palladio, bridge of 174
Pantheon, roof of principal room 118
Parabola, the curve of equilibrium for uniform load 31
———— cubic, how to describe 31
———————— the curve for a dome uniformly loaded 32
—— common, strongest form for a column ... 59
———————— how to describe 116
—— centre of gravity of 18
Paraboloid, ditto 18
Parallelogram of forces, on the 3
Parapets of bridges, on the 202
Partitions, on the construction of 152
———— weight of a square of 153
———— descriptions of designs for 154
Pear tree, experiments on the stiffness of ... 72
Pediments, angle of... 102
Pencil cedar 294
Philadelphia Bridge 179
Piers of bridges, on 193
———— Mr. Telford's method of forming ... 194
Piles and pile planks 172
—— durability of 255
Pillars, strength of 80
Pinaster, on the 290
Pine (see Red Fir)
—— experiments on the stiffness of 73
———————— on the strength of 67
—— pitch, on the 289
—— American, on the 289
—— Scotch, on the 285
—— yellow, on the 286
Pins, a good method of connecting timbers ... 216

PAGE

Pipe-worm, on the 253
Pitch of a roof 102
—— effect of, in seasoned wood 242
—— pine, on the 289
Pith of a tree 225
Plane tree described 270
—— experiments on the stiffness of 72
———————— on the strength of 73
Polygon of forces, on the 15
Poona 280
Poplar, kinds of, described... 283
———— experiments on the stiffness of 72
———————— on the strength of 67
Position of beams, effect of the 11
Posts, stiffness of 58
—— experiments on 62
—— practical rules for scantlings of 61
—— story, tables of scantlings for 81
Practical rules for the stiffness of beams 42
———————— strength of beams 53
———————— for columns, posts, &c. 61
Preservation of straps, on the 223
———— of timber, on the... 247
Pressure of beams, how to calculate 3
Pressure, direction of, how found 4
Pressures in framing, how to measure 6
Prevention of decay in wood 247
———————— rising damp in walls 247
Principal rafters of a roof, on the 131
———————— joints for 213
———————— straps for 220
Properties of wood 224
———— table of 295
Protection of timber 252
Purlins for roofs, rules for 134
———— table of scantlings for 140
Pyrites a good material to prevent decay ... 248

Q

Quarter partitions 152
Quassia, infusion of, used to preserve wood from worms 253
Queen-posts, rules for 128
———————— straps for 220
Quicklime a cause of decay 242

R.

Radius of curvature for bridges 199
———————— of a beam 40

PAGE

Rafters, principal, rules for 131
——————— joints for 213
——————— straps for 220
——————— common, rules for 134
——————— tables of scantlings for 141
Railing for bridges, on 202
Raking shores 170
Red fir described 285
Removing centres, on 163
Rennie's experiments on the resistance to crushing 56
Renton's ditto 56
Repairs after dry rot 251
Resilience of timber, on the 66
Resistance of timber, on the 35
——— to flexure the most important 37
——— to tension 37
——— to cross strains 38
——— to compression 55
——— of columns and posts 58
——— to crushing 77
——— of joints 57
Resolution of forces, on the 3
Resultant of a system of forces, to determine ... 14
Ribs, curved, strength of 64
——————— roof with 115
Riga oak 266
—— fir 285
Rings, annual 224
Rise of wooden arches 189
Rivers, on the firmness of the beds of 186
——— velocity of 186
Roadway of bridges, on the 185
Road scrapings in mortar a cause of dry rot ... 245
Robison, Professor, his experiments on detrusion 54
Rock elm of Canada 276
Roman tiling 110
Rondelet's experiments on crushing 56
Roof, strains in a truss for, how measured ... 6
—— combined cast- and wrought-iron 301
—— of Abbey Mills Pumping Station 302
—— wrought-iron 302
—— to find the horizontal thrust of 20
—— shed, on the pressure of 21
—— dock, remarks on 29
——————— description of 122
—— on the construction of 101
—— on Gothic 123
—— on the pitch of 102
—— description of, for various spans 107
—— with curved ribs 115
—— without a tie-beam, on 188

PAGE

Roof of Westminster School 124
——————— Hall 124
—— description of, at Bombay 112
—— of Basilica of St. Paul's at Rome 109
—— of Theatre d'Argentina at Rome 110
—— of the Riding-House at Moscow 117
—— of Great Northern Railway terminus ... 117
—— tables of scantlings for 137
—— ancient and modern 109
—— Parkhurst Prison 111
—— Leghorn Cathedral 111
—— Drury Lane Theatre 108
—— Christ's Hospital 111
—— Academy at Florence... 111
—— Riding-School, Modena 121
—— Exchange at Gonoa 121
—— St. Martin's-in-the-Fields 122
—— Manchester Assize Courts 125
—— Churches of Norfolk and Suffolk 125
—— Hampton Court and Eltham Hall 124

S.

Salt, effect of, in preventing dry rot 248
Sand, specific gravity of 299
Sanded painting more durable than common ... 252
Sap, on the motion and nature of... 225
—— confined, a cause of dry rot 246
—— wood, on the nature of 226
——————— proportion of, in trees 226
Sawing timber down the middle 87
Sawn timber neither so strong nor so durable as split 259
Scaffolding 167
Scantlings, of floor timbers 97
——————— of roof timbers 137
——————— of story posts 81
Scarfing, on 208
Schaffhausen Bridge 180
Schuylkill, bridge over 179
Scorching timber, remarks on 233
Scotch pine 285
Screws, uses of 222
——— resistance to drawing 223
Sea water, effect of, in preventing decay 248
Seasoned, term limited 239
Season for felling trees 228
Seasoning timber, on 229
—— water, on 231
—— Langton's method of 234

PAGE

Seasoning timber, Duhamel's experiments on ... 235
——— Couch's experiments on 236
——— Wiebeking's experiments on ... 236
——— Bishop Watson's experiments on ... 237
—— on the laws of 238
—— is the best method of preserving timber ... 247
—— in the frame not to be recommended ... 247
Sepping's framing for dock roofs 122
Septa of woods, on the 259
Serlio's floors of short timbers 95
Settlement of beams, quantity of, allowed for in the rules 43
——— bridges 189
——— unequal, effect of 154
Shearing strain 54
Shed roofing, pressure of 104
Sheet-piling 172
Ship worm, to prevent the ravages of 253
Shoes, cast-iron 216
Shoring 170
Shrinkage of timber, effect of 207
——— by seasoning 231
Silver grain, on the 259
—— fir 290
Single-joisted floors, on 84
——— table of scantlings for ... 99
Slates used to prevent damp walls 247
—— on the specific gravity of 299
Slating, pitch for, and weight of 103
Smeaton's remedy against worms 254
——— on centres 161
Sockets, iron 219
Spanish mahogany described 277
Span of arches of wooden bridges 188
Specific gravity of woods, table of 296
——— of various materials, table of ... 298
Spires of wood 150
Split timber 259
Spruce fir described 287
Spur of a crane 12
Stability of position 1
——— from equal resistance 2
Staging 168
Steaming timber, on 232
Stiffness defined 36
——— knowledge of, most important in carpentry 37
——— distinguished from strength 36
——— to resist tension, on 37
——— to resist cross strains 38
——— experiments on 43

PAGE

Stiffness, remarks on 38
——— comparative, of woods, table of ... 295
Stones, specific gravity of various 299
Stone vaulting 303
Stonework, weight of a cubic foot of 300
Story-posts, tables of scantlings for 81
Stoves a cause of decay 245
Straining beams, on 132
——— sill 108
Strains in framing, how measured 6
Strains on beams laid horizontally 22
Straps, on 220
Strength defined 36
——— distinguished from stiffness 36
——— to resist tension 38
——— of iron 69
——— to resist cross strains 50
——— experiments on 73
——— of columns, posts, &c. 58
——— of curved ribs 64
——— of joints 57
Structure of woods, on the 259
Struts, how distinguished from ties 12
——— rules for 133
Strutting 171
Stucco, an excellent preventive of damp 247
Sulphate of copper and of iron used to prevent dry rot 251
St. Pancras Station, staging for 169
St. Swithin's Church spire 151
Suspending pieces, on 215
——— straps for 220
Sycamore described 270
——— experiments on the stiffness of 72
——— experiments on the strength of ... 73

T.

Table of tensile strength 67
——— transverse strength 68
——— cohesive strength 68
——— stiffness 72
——— crushing strength 77
Table of the classes of woods 260
——— properties of wood 295
Tables of scantlings, &c. 81, 97, 137
——— specific gravities 296
Tar, effect of, on unseasoned wood 246
—— coal, of use to preserve timber 251
Teak described 279

	PAGE
Teak, experiments on the stiffness of	72
—— experiments on the strength of	67
Templets	94
Tension, on the resistance to	37
Teredo navalis	253
Termites	254
Texture, close, a cause of durability	257
Thatch, pitch for a roof of	103
Theatre d'Argentina, roof of	110
——— in Birmingham, roof of	108
——— at Ancona, roof of	110
Tholas	253
Thrust of an arch	192
Tie-beam plate, cast-iron	219
Tie-beams, on	129
——— remarks on putting blocks under ...	130
——— remarks on cambering	131
Ties, how distinguished from struts	12
—— on the joints of	215
Tiles, pitch for and weight of	103
Timber, knowledge of its resisting power necessary	35
——— definition of...	224
Timber bridges, on	174
——— principles of constructing	175
——— nature of	224
——— on felling	227
——— on seasoning	229
——— on the decay of	241
——— kinds of, most subject to decay	244
——— should not be suffered to float in docks ...	244
——— should not be used for supporting heavy stonework	246
——— on the prevention of decay of	247
——— Kyan's process for the preservation of, from dry rot	249
——— Burnett's process for the preservation of, from dry rot	252
——— to preserve when exposed to the weather	252
——— to preserve from worms and insects ...	252
——— durability of, in different states	255
——— durability of, experiment on	258
——— split more durable than sawn	259
——— properties of	224
——— table of the properties of	295
——— specific gravity of	296
——— on the resilience of	66
Time required to dry and season timber	231
Toughness of woods	261
——— table of the comparative	295
Trajan's Bridge	174
——— durability of piles of	255
Trapezium, centre of gravity of	18
Trees, on felling	227
—— old, often decayed	227
—— rapidly grown, soon decay	244
—— from close forests, subject to decay... ...	244
Trenton Bridge	179
Triangle of forces	4
Trimmers described	84
Trimming joists, on the scantlings of	85
Truss of foot-bridge	175
—— of roof, combination of timber with iron ...	112
—— of wrought-iron roof	302
—— of wrought- and cast-iron roof	301
—— to measure the strains in	6
Trussed girders, remarks on	88
——— roofs...	106
Trussing for bridges, principles of...	195
Tubes, on the strength of	52

U.

Ultimate stress on posts	81
Untrussed roof	104
Uniform curvature in bridges	199

V.

V-roof	104
Vaulting of King's College Chapel, Cambridge ...	303
Velocity of rivers, on the	188
Ventilation as a prevention of decay	248
Viaduct, College Wood	205
——— St. Germans	205
——— Elwell	205
——— South Wales Railway	206
Voussoirs of bridges	157

W.

Waling-pieces	172
Wall-plates, dimensions of...	94
Walls, to prevent moisture rising in	247
—— should be allowed time for drying	247
Walnut tree described	278
——— experiments on the stiffness of ...	72
——— experiments on the strength of ...	67
Washes, use of, in preventing dry rot	248

PAGE

Water, presence of, essential to the decomposition of wood... 242
Waterloo Bridge, centre of 161
Water-seasoning, on 231
Water-way under bridges, on the 185
Weather, to preserve wood exposed to 252
Weight, effect of 3
——— of timber in different states 235
——— of materials, tables of 298
Westminster Abbey vaulting 310
Westminster Hall roof 124
Weymouth pine 289
Wet rot 243
Whale oil preserves timber from worms 254
White deal described 287
White ants... 254
Width of bridges, on the 185
Wiebeking's table for rise of bridges 191
Willow, experiments on the stiffness of 72
——— experiments on the strength of 74
Wind, force of 103
Wood, on the cohesive force of 38
—— experiments on the stiffness of 72

PAGE

Wood, experiments on the strength of 74
—— properties of 224
—— structure of 224
—— on the decay of 241
—— on the preservation of 247
—— on the preservation of, from worms... ... 252
—— on the durability of 255
—— experiment on the durability of 258
—— on the structure and classification of ... 259
—— table of the properties of 295
—— on the specific gravities of 296
Wooden bridges, on 174
——— on the principles of constructing 195
Woody fibre... 242
Worms, to preserve wood from, ... 252
——— ship 252

Y.

Yellow fir described 285
——— pine 289
Young, Dr. Thomas, his formula for the resistance of columns 60

HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE, LONDON.

00080074

Digitized with financial assistance from the
Observer Research Foundation
on 25 April, 2019